STUDIES OF THE EFFECT OF PHYSICAL PROPERTIES OF MOULDING SAND ON SOUNDNESS OF CASTINGS

A DISSERTATION
SUBMITTED IN PARTIAL FULFILMENT
FOR THE DEGREE OF

M. Sc. (Engineering)

IN
MECHANICAL ENGINEERING
(INDUSTRIAL ENGINEERING AND DESIGN)

BY

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ALIGARH

MAY, 1980

CERTIFICATE

This is to certify that the dissertation entitled " Studies of the Effect of Physical properties of Moulding sand on Soundness of Casting" which is being submitted by Mr. Shahabuddin in partial fulfilment for the award of the degree of M.Sc. (Engineering) in Mechanical Engineering (Industrial Engineering and Design) is record of bonafied work carried out by him under our guidance and supervision. To the best of our knowledge and belief, the matter embodied in this dissertation has not been submitted elsewhere for the award of any other degree or diploma.

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A C K N O W L E D G E M E N T

It would be ponderous to mention the invaluable help, assistance and guidance Mr. M. Hameedullah (Lecturer, Mechanical Engineering department) has extended to me in this work, despite of his busy schedule. He has been sincere methodical and painstaking in handling the work.

Mr. M. Wasim Abbas (Lecturer, Mechanical Engineering department) my Co-Supervisor deserves a distinguished vote of thanks for helping me out in the completion and submission of my dissertation.

Warm thanks are due to Foundary shop staff members, who not only extended practical help in carrying out the time studies but tolerated many of my evident eccentricities at times during the course of this work.

Shahabuddin

May, 1980 (SHAHABUDDIN)

A B S T R A C T

The study of the effect of physical properties of moulding sand on the soundness of castings apparently seems to be quite simple but the experimental procedures involves, required considerable efforts. This is due to difficulties in maintaining similarity in the laboratory test specimen conditions and the actual mould conditions.

In the present work an attempt has been made to maintain the similarity in the laboratory test conditions, and the actual mould conditions by ramming both in the same hardness. One more difficulty comes into picture two hardness of ramming is found to be varying at different points when hand ramming is performed. The variation was found to be in a random manner so that hardness of ramming of mould follows statistical laws. This variation is found to follow a normal law. Therefore mean value of hardness of ramming was considered, and the test specimens were rammed to this value and for various moisture contents, green permeability , green compression strength, and green shar strength were determined.

In the first phase of this work the effect of mulling time on various physical properties of moulding sand with the variation in clay content and moisture content in Ganga River Silica Sand has been studied and test results have been reported in Chapter II. The effect of hardness of vary ramming on physical properties has also been reported in the same chapter.

A detailed study of the effect of various parameters like pouring temperature , gating system etc., on the casting defects. Soundness of casting is attributed to mechanical properties. This has been studied keeping all the parameters constant and studying the effect of physical properties of moulding sand on tensile strength, Brinell hardness number and casting density on a predetermined alumini-um specimen casting.

A Cause and effect type relationship has beendeveloped using multiple regression analysis. In the present study the effect are taken to be the atributes of castings. These atributes are casting soundness parameters. The independent variables which could be treated as causes for the casting soundness parameters are taken as physical properties of moulding sand. Developing relationship between dependent variables individually with independent variables through multiple regression technique as an attempt has been made to develope a definite mathematical relationship between various parameters .

C O N T E N T S

CHAPTER - I

INTRODUCTION

Moulding sand actually is a mixture of silica sand, a suitable bonding material, and certain additives combined with water. There are four requirements of a good moulding sand. These are :

a. It must be highly refractory in order to withstand the high temperatures of the molten metal.

b. It must be sufficiently cohesive so that it will retain a given shape when packed into a mould.

c. It must be permeable so as to allow entrapped gases to escape.

d. It must collapse so as to permit the metal to shrink after solidifying.

Refractoriness is provided by the sand. Bond is provided by moistured clay, and permeability is a function of the sand particle size clay content and moisture content. Increasing clay content and decrease in particle size decreases the permeability. Thus it is necessary to provide and maintain a proper relationship between grain size, clay content, moisture content and organic matter in order to have a satisfactory combination of, and usually a compromise among, strength, refractoriness, permeability, and collapsibility. Good moulding sand normally should contain 8-14 percent clay and require 4-8 percent moisture as is cited by A.F.S. (1). The size of the sand particles is important. For small castings, and those requiring a smooth finish, fine grain sand is desirable. For larger castings it is almost essential to use a sand of coarser grain in order to provide the greater permeability required to vent the larger amount of gases which are produced when such moulds are poured. In most cases a proper range of grain sizes is desirable.

Casting in moulds made by any of the usual sand moulding processes, is practiced with aluminium alloys. Green sand moulding with conventional moulding equipment is used to greater extent, although dry-sand moulds are preferred where large or intricate work is involved.

Both natural and synthetic sands of the types are employed in green sand moulding for aluminium castings. Whether a natural or synthetic sand is used, good sand conditioning is required. Excessive moisture, lumps, clay balls or other matter may cause serious casting defects. Reaction of the molten metal with excess moisture in the sand may result in reaction porosity, a concentration of small spherical voids usually just under the casting skin. Clay balls in the sand may explode when covered by molten metal and cause pits or small blows. Severe generation of steam within the mould, together with turbulent metal flow may result in extreme gas porosity.

Lack of metal soundness in a casting is one reason for lower than optimum mechanical properties. The foundryman, by using a sufficient number of foundry techniques such as gating, risering, chills, padding, and thermal gradients can usually produce soundness even in exceedingly difficult cases of poorly designed castings. However, if certain design principles are observed, the job of producing soundness and uniformly good properties can be made much easier and less costly.

Metallurgically an ideal casting is that which possesses optimum properties and is produced with the and is produced with highest casting yield. The yield is defined as the %cent ratio of the weight of the finished product to the weight of the poured casting . Metallurgically important properties of finished castings could be described as :

1. Surface
2. Size,
3. Structure,
4. Soundness, and
5. Stress.

Casting quality depends on the optimum being obtained in one or more or all of these properties and variations from the optimum are related directly to some aspects of metals or mould behaveour and indirectly to the numerous process variables. A good surface finish is an important factor with the castings proper sand , proper ramming of sand in a mould, proper mould hardness, good moulding boxes used and proper temperature of metal and good teeming of metal with ensure that the castings are free from surface defects.

The present work deals with study of effects sand properties on the soundness of casting. It includes development of emperical relationships for soundness with various sand parameters, by multiple regression analysis.

To study the soundness , of castings, tensile strength of castings, Brinell hardness number and casting density have been chosen as soundness parameters as the casting density takes case of internal defects such as blow holes, pinholes etc., and tensile strength Brinell hardness takes care of soundness with metallurgical point of view, such as uniformity in structure etc.

The most difficult job in correlating the soundness of castings with the moulding sand properties is the difficulty in maintaining similarity in the mould conditions and laboratory test conditions. This seems to be the main reason for lack of much literature in this direction .

In this work an attempt has been made to maintain the similarity in test conditions and mould conditions by ramming the test specimen as well as the mould to the same hardness. Variation of tensile strength, Brinell hardness number and casting density of aluminium test specimens with the variation of moisture content, permeability, compression strength, shear strength, bulk density on the casting soundness has been studied.

CHAPTER - II

MOULDING SANDS

Moulding sands consists of silica grains held together by some bonding material, usually clay or bentonite.

Naturally bonded sands are mixtures of silica and clay as taken from the pits. Modification may be necessary to produce a satisfactory mixture. This type of sand is used in gray iron, malleable iron and non-ferous foundry (except magnesium).

Synthetically bonded sands are produced by combining clay-free silica a sand with clay or bentonite. These sands can be compounded to suit foundry requirements. They are more uniform than naturally bonded sands but require more careful mixing and control. Steel foundries use this type of sand.

Moulding sands are actually mixtures of three or more ingradients. A green sand always contains clay and water as well as the principal sand constituent, silican oxide , SiO_2 . These three constituents provide the bulk and plasticity required of the moulding sand. A number of other materials may be present or may be added to the sand to enhance certain of the properties, but first consideration must be given to the three basic ingradients.

2.1 Effect of sand ingredients on properties Moulding sand :

Each of the ingredients can have important effects on the properties. Since one of the principal ingredients of moulding sands are the silica sand grains, their effect will considered first.

Effects of the sand grains :

Casting surface finish, mould permeability, sand strength, refractoriness, and expansion characterstics are all influenced by the sand grains portion of the mixture. It is concluded by the author in this work that the green permeability and green strength influenced by the sand grains portion of the mixture.

Sand grains and permeability :

Coarser sands with greater void space have greater permeability than finer sands. In addition to average grain size, the grain distribution has a pronounced effect on permeability. A sand with many fines and a wide range of particle size will have low permeability when compared with one of the same average finess but having only one size of a few sizes of grains present. If a moulding sand is contaminated with core sand of greater fineness, the permeability may be seriously lowered. Other properties are so dependent on sand -grain distribution that this factor has received much attention. According to Dietert (1) the most permeable sands are those having the narrowest distribution range, i.e. , 1-, 2-, or 3- sieve sands and also having a minimum fine material such as silt or clay present. Permeability is also promoted by the rounded type of sand grains.

It is observed by the author in this work that the grain size distribution has a pronounced effect on green permeability.

Sand grains and strength :

The strength of moulding sand is greatly dependent upon the surface area of the sand grains available for bonding. Fine sands present more surface area and can develop high strength, but of course more clay is required. Size distribution also influence this factor for the same reason. Wide size distribution favour strength, while narrow distributions reduce strength. Angular sand grains promote greater strength than do rounded grains in moulding sands.

Sand grains and refractoriness :

Refractoriness, highest fusion point, seems to be obtained in these sand grains of maximum purity and size. Washed and dried, white silica sands of AFS numbers 30 to 45 are regarded as having highest refractoriness with fusion point above 3000F as stated by Fairfield (2). Impurities which discolour silica lower its fusion point. Finer grains appear to be more easily fused than coarser ones. Where maximum refractoriness is required as in steel moulding sands, the coarse, high purity silica sands are used to advantage.

Sand grains and sand expansion :

Expansion of the heated sand is regarded as being least when a favourable grain size distribution exists. A wide distribution or double peaks in the distribution curve are thought to cause expansion problems, because of the dense packing of the grains. Fine sands also expand more, probably for the sand as is mentioned by Dietert (3). Four and five sieve sands are presently regarded as favourable one from an expansion view point.

Clay and sand strength :

For a given clay type and content, there is an optimum water content control of moisture in the moulding sand, so that the best properties are developed (not only strength) thus is the basis of sand control. According to Narayana (4) green compression strength green shear strength increase with increase in water/clay ratio of 0.4 and subsequently decreases with further increase in water/clay ratio.

It is stated by Ganapathinem etall (5) for a given clay percentage, one can infer that increase in the water clay ratio causes the green compression strength to increase, reach a maximum and then decrease with further increase in the water /clay ratio, irrespective of the clay percentage, green compression strength of the sand mix attains a maximum value around 0.3 water/clay ratio, and at a given water/clay ratio, the green compression strength increases with increase in clay percentage. For a particular clay percentage, the green shear strength increase with increase in water/clay ratio, reaches a maximum value at a water clay ratio of about 0.3 and then decreases with further increase in the water/clay ratio, and green shear strength increases with increase in clay percentage at a particular water/clay ratio. The green hardness increases with increase in water/clay ratio, for a given percentage reaches a maximum around a water/clay ratio of 0.3 and decreases with further i increase in the water/clay ratio. It can also observe that the hardness increases with increases in the clay percentage at any fixed water/clay ratio.

For a given clay percentage, with increase in water/clay ratio, bulk density gradually decreases and reaches a minimum and subsequently increases. This trend is observed at all bentonite percentages used in this investigations. It also indicates that the bulk density is minimum at a water/clay ratio of 0.5 for all the clay percentages employed.

The chandipur river mouth sand containing high% of silica and a tolerable quantity of iron oxide alumina and alkali oxides has been tested by Mohanty etall(16) for its physical and chemical properties in relation to its suitability as moulding sand. The test results obtained recommended for use of this t sand in moulding sand for steel casting. Using this sand along with binders and additives, moulding sand for steel casting was prepared and its physical and chemical properties were determined and were found satisfactory.

Narayana & Ramkrishnan (17) has concluded that the mutual effect of the physical properties of foundry sand on each other at different water/clay ratios at 3, 6, and to ram levels. The following resulats were obtained :

i Green compression strength Vs green shear strength and green permeability Vs bulk density show a linear trend,

ii. green compression strength Vs green hardness and riddled compactibility; shatter index Vs riddled compactibility; green compression strength Vs dry compression strength show quadratic relations, and

iii. green permeability Vs green hardness and riddled compactability; green hardness Vs A.F.S. flowability show decreasing trend with the increase of the other and green hardness increases with increase in bulk density.

Experiments were carried out by Subba Rao & Ram mohan (18) to study the effect of water/clay ratio ranging from 0.2 to 1.0 on the physical properties of homogeneous sand mixes containing different particle size silica grains and various percentage of bentonite (3% to 11%). Attempts to interrelate the various physical properties of bentonite bonded homogeneous mixes indicate that linear relationship exists between green compression and green shear strength, and compactability, GF flowability and riddled density are linearly interrelated.

It is stated by Radhakrishnan etall(19) that compression and shear strength , hardness, permeability, bulk density, riddled density, flowability or compacta-bility of synthetic clay bonded moulding sand mixtures in the green state can be expressed as a function of clay and water percentages for a given sand.

They studied the properties of moulding sands for bentonite contents varying from 4 to 10% in steps of 2% and for water/clay ratio ranging from 0.2 to 1.0 with intermediate values at 0.3, 0.5, and 0.8. They have developed the established some interrelationship between properties of a given moulding sand. Experimental data by Subba Rao & Rama mohan (20) indicate that , for a given clay content, green compression strength and green shear strength reach a maximum around a clay/water ratio of 2.5. Green hardness attains a steady value ath the sand clay/water ratio. Permeability attains a maximum and bulk density a minimum at a clay/water ratio of 1.5.

Experiments were carried out by the author to study the effect of clay varying from 14 to 18% and water content from 4 to 8% on various phusical properties of the clay-bonded natural mouldingsands. In figures 6 to 9 6mts, 8mts, 10mts, 12mts mulling time are shown the effect of moisture content and clay percentage on various physical properties of clay bonded sands.

From fig. 6 one can infer that at a given moisture content, the green compression strength increases with increase in the clay percentage.

The shape of the curves of fig. 7 obtained on plotting green shear strength versus moisture content, for a particular clay percentage, is similar to the one obtained on plotting green compression strength versus moisture content at a constant clay content. From the figure one can observed that at a given moisture content, the green shear strength increases with increase in the clay percentage.

A study of fig. 8 indicates that the green hardness increases with increase in the clay percentage at any fixed moisture content.

From fig-9, one can infer that for a given clay percentage, with increase in moisture content, bulk density gradually decreases as shown in figure, reaches a minimum and subsequently increases. This trend is observed at all clay percentages used in this investigations.

Clay content and permeability :

Permeability is reduced by fine material in the sand. Clay content also influences the bulk density achieved by the sand during ramming. According to Narayana etall (4) that green permeability increases with increase in water/clay ratio and attains a maximum around 0.5 water /clay ratio andsubsequently decreases with further increase in water/clay ratio; bulk density on the other hand reaches a minimum at 0.5 water/clay ratio. It is observed by Ganapatiram etall (5) that for a given clay percentage, with increase in water/clay ratio, bulk density gradually decreases and reaches a maximum and subsequently increases. This trend is observed at all bentonite percentages used in this investigation. It also indicates that the bulk density is minimum at a water/clay ratio of 0.5 for all the clay percentages employed.

For a given clay percentage, permeability increases with the increase in water/clay ratio, attains a maximum and subsequently decreases on further increase in the water/clay ratio. The permeability attains a maximum value around a water/clay ratio of 0.5 for all the clay percentages studied and for a given water/clay ratio permeability decreases with increase in clay content.

It is studied by the author that from the fig.5 one can conclude that for a given moisture content green permeability decreases with increase in clay content.

Clay content and expansion :

According to Dietert (3) clay content of 10 to 14 percent in the sand mixture are accompanied by minimum confined-expansion values, 0.03 to 0.04 inch per inch as measured at $2500^{\circ}F$. High clay contents together with the proper amount of water and ramming of the sand thus favour thermal stability according to this theory(2)

Clay content and other properties :

So many properties are influenced by the clay type and amount in moulding sands that it is not possible to consider them all here. Some sands have been found resistant to flow during moulding. Soft spots and porous creap in the mould result in casting swells and roughness (6). Mold hardness tests of the mould cavity surface are useful in studying the uniformity of sand flow during moulding.

Sand mixing problems are also related to the clay ingredient. Good mixing is supposed to cause uniform coating of the sand grains s with clay.Effect of moisture content

Effect of Moisture Content :

It is evident from the preceding discussion that close control of the moisture content of moulding sands is exceedingly important because of the many properties affected by it.

A series of experiments conducting by the author(7) that the green compression strength, green shear strength decreases with increase in moisture content. Green permeability and bulk density increases with increase in moisture content and attains a maximum but consequently decreases green permeability with further increase in moisture content.

Effect of mulling time :

Experiments has carried out by author (7) that for the same percentage of sand, clay and water, the physical properties of the sand mixture will vary with the mulling time as well as with the method of addition and the type of muller.

In figs 10 to 14 are shown theaffect of moisture content and clay percentage on various physical properties of clay bonded moulding sands.

Permeability :

From Fig. 10 one can conclude that for a given clay percentage, with increase in moisture content, green permeability increases as shown in figure, reaches a maximum and subsequently decreases.

Green compression strength :

From Fig. 11 one can infer that for a given percentage of clay, increase in moisture content causes the green compression strength to decrease, reaches minimum and then increases with further increase in the moisture content.

Green shear strength :

From Fig. 12 one can observe that for a given percentage of clay, increase in moisture content causes the green shear strength to decrease, reaches a minimum.

Green Hardness :

As study of Fig. 13 indicates that the green hardness increases with increase in moisture content, for a given percentage reaches a maximum and decreases with further increase in the moisture content.

Bulk Density :

For a given clay percentage with increase in moisture content, bulk density increases as shown in Fig.14 reaches a maximum with further increase in moisture content for all the clay percentages.

There are two methods of adding clay and water to the sand. In the first method, first water is added to sand followed by clay, while in the other method, clay addition is followed by water. It has been suggested that the best order of adding the ingredients to a clay bonded sand is sand with water, followed by the binders. In this way, the clay is more quickly and uniformly spread on to all the sand grains. An additional advantage of this mixing order is that less dust is produced during the mulling operatio operation.

It has observed by author (7) that the physical properties of moulding sand such as green compression strength, green shear strength and bulk density increases with increase in mulling time and attains a maximum value as moisture content remains the same. At the sand condition green permeability decreases with increase in mulling time.

Effects of sand conditioning :

Effective moulding sand preparation usually consists of certain steps, including the following :

1. Removal of foreign material, principally fines, metal, and hand lumps, as the sand is prepared for reuse.
2. Adequate mixing and tempering . Mulling or other mixing of the sand to distribute the clay, water and additions should be continued until optimum sand properties are developed. Certain mixers are much more, potent than others. Undermixed sand may have a very non-uniform distribution of ingradients.
3. Aeratong, consisting of separating sand grains and of riddling, screening or beating the sand, is practised to promote better moulding results.
4. Control of sand temperature. Cooling of sand temperature is desirable since hot sand over 100°F causes moulding difficulties, for example , sticking, drops, etc.

Effect of Moulding method :

Moulding by jolting , ramming, squeezing , or sand slinging can produce different properties as is cited by Heive and Rosenthal (6). According to him the green-sand properties of the 3-ram sand test equivalent to those of 50 to 80 psi of squeeze pressure. The difficulty of attaining uniformity oframming is present in any method of moulding and can be detected by hardness surveys of the mould surface. Non uniform hardness is believed to reflect undesirable variations in the properties. Hence the standard A.F.S. test results do not reflect the properties of the sand in the mould unless some considerable pains are taken to correlate them.

Casting Variables :

The casting produced are in the end the principal criteria of what constitutes a good moulding sand. High pouring temperature of the casting alloy, 3000 to 3200F for steel as an example, places much greater emphasis on the thermal resistance of the sand. For the same reason small castings are less demanding than large ones , being solidified before the mould surface is significantly heated. A casting that remains molten long enough so that the heated up to the liquid metal temperature requires great thermal stability. Heavy castings and high pouring temperatures necessitate larger additions in conditioning the sand for reuse.

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Mulling time = 6 mts

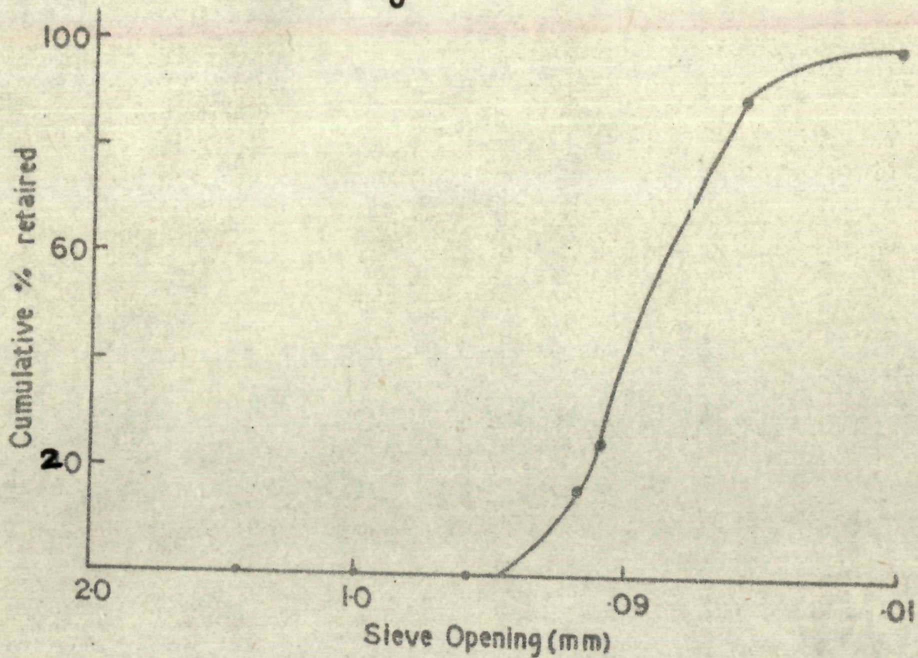


FIG: Cumulative Grading Curve

Mulling time = 8 mts

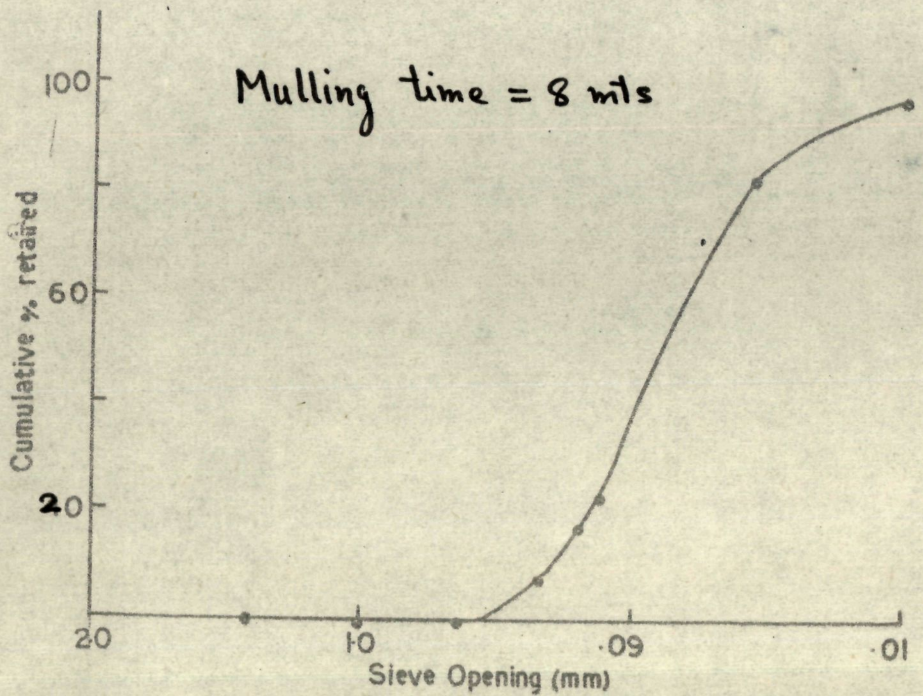


FIG: Cumulative Grading Curve

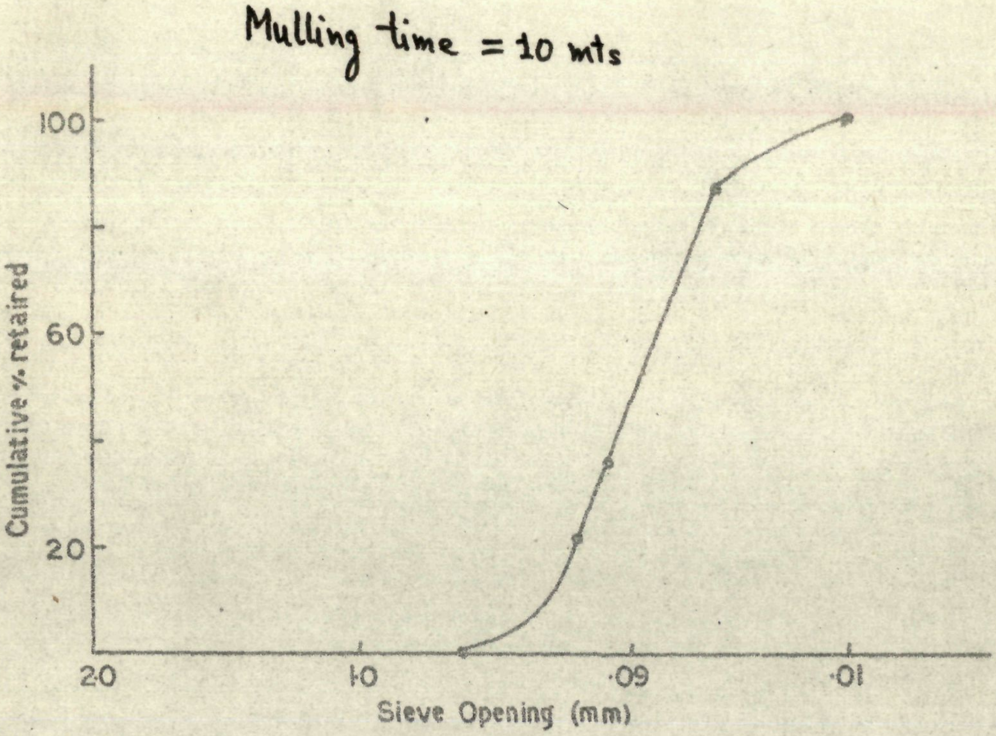


FIG: Cumulative Grading Curve

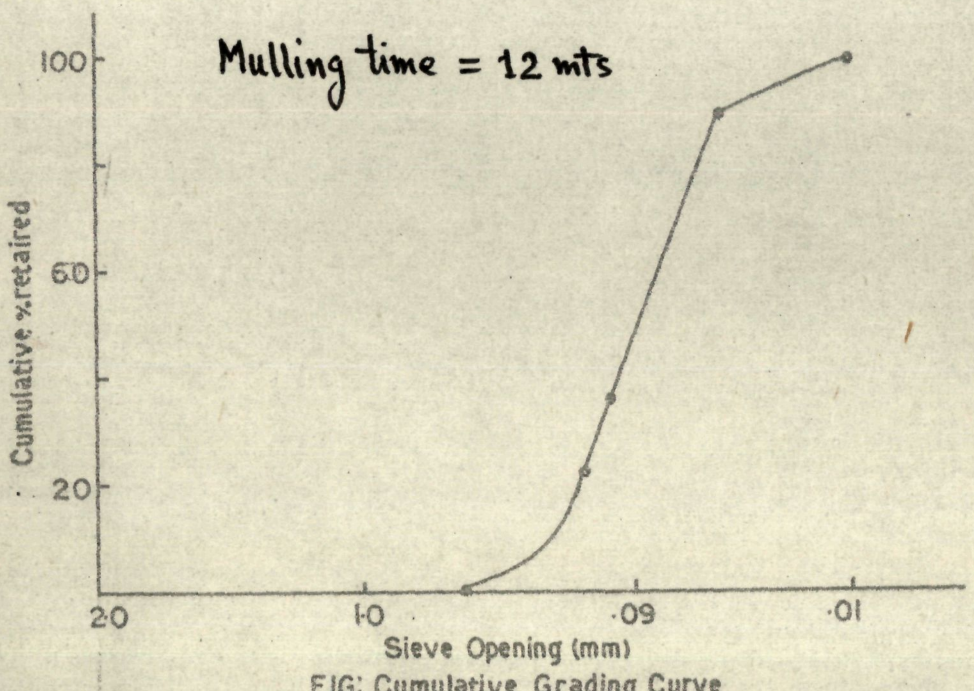


FIG: Cumulative Grading Curve

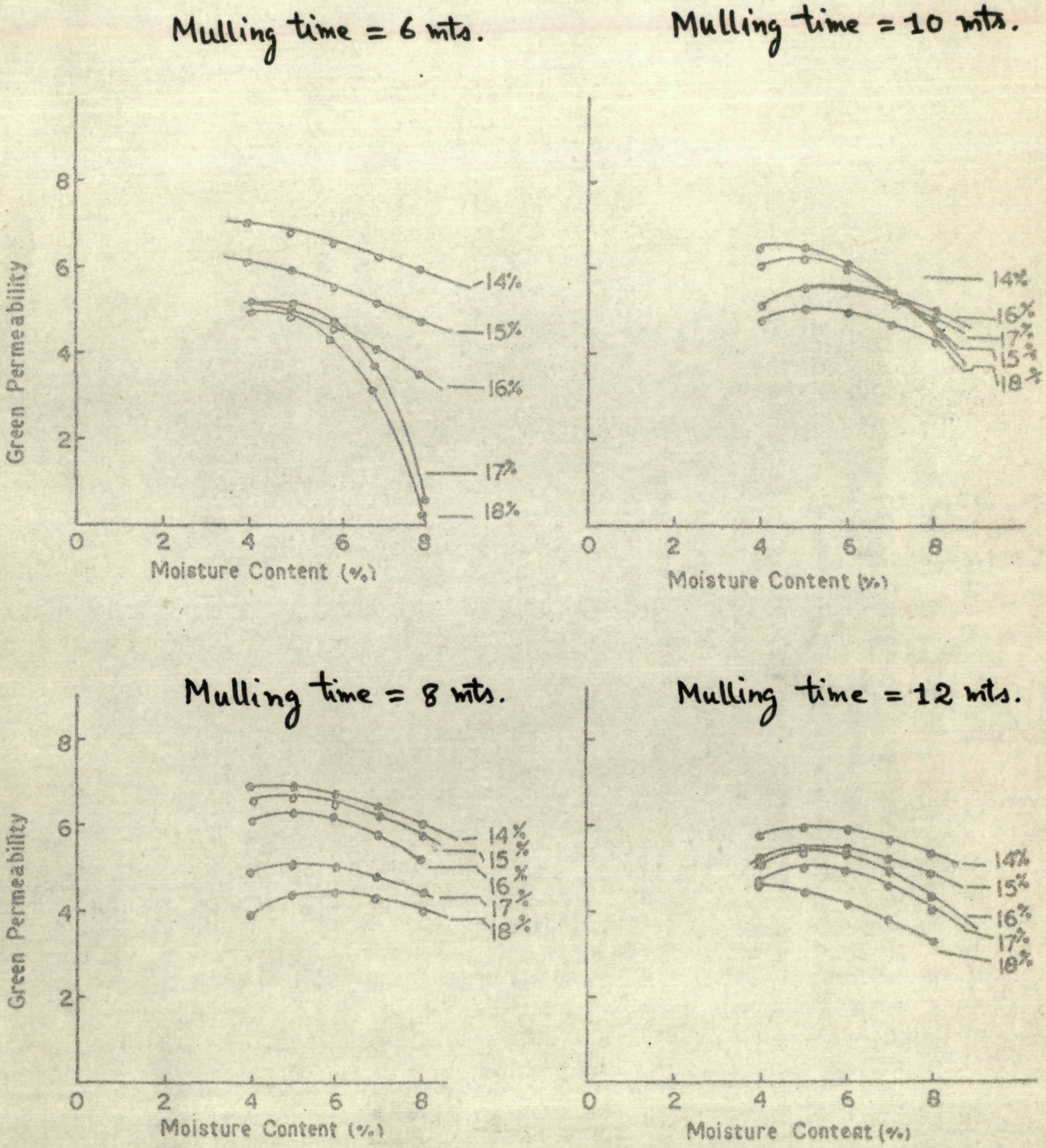


FIG : Variation of Green Permeability with moisture content.
(at different clay percentages)

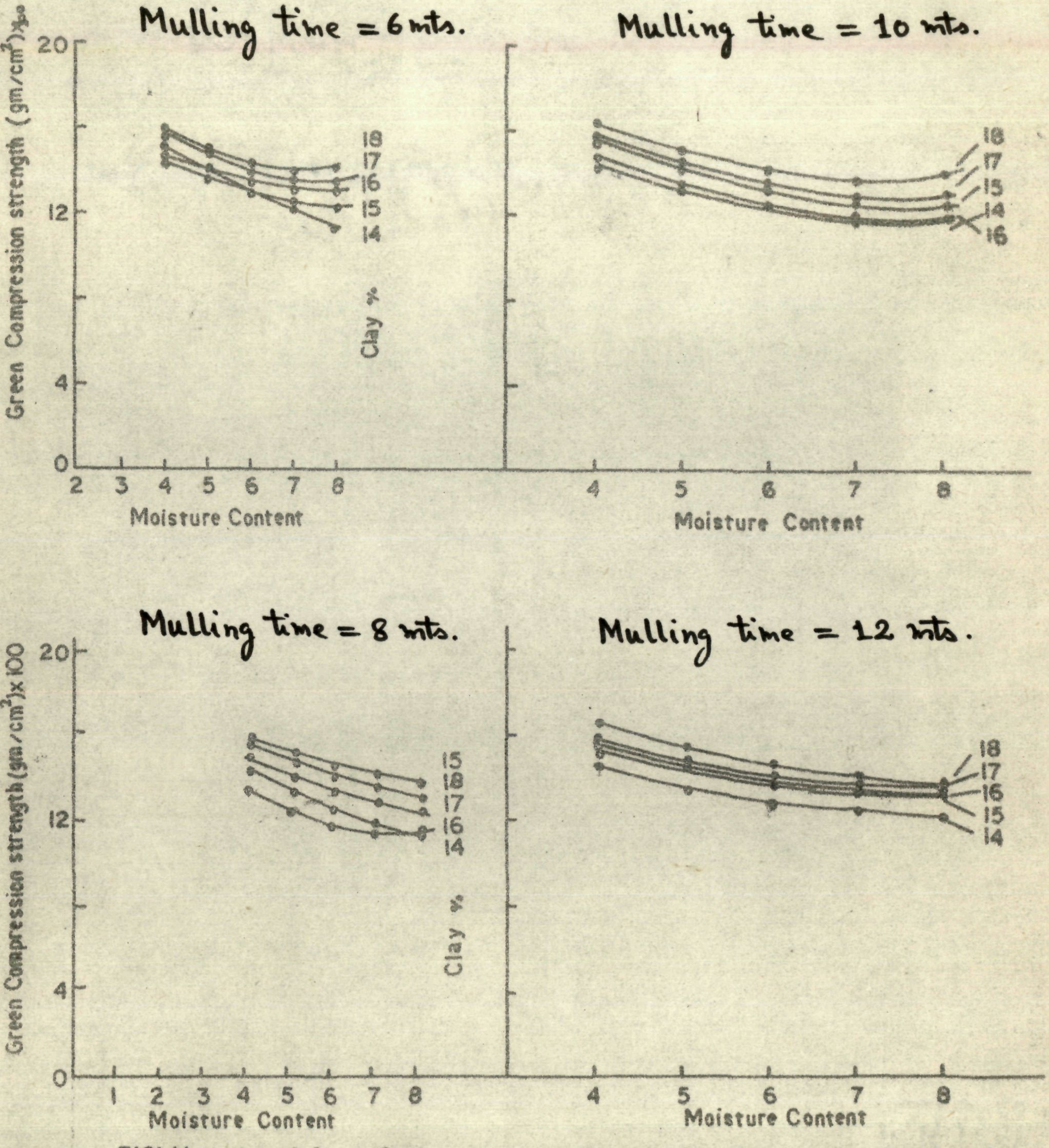


FIG: Variation of Green Compression strength with moisture content.

(at different clay percentages)

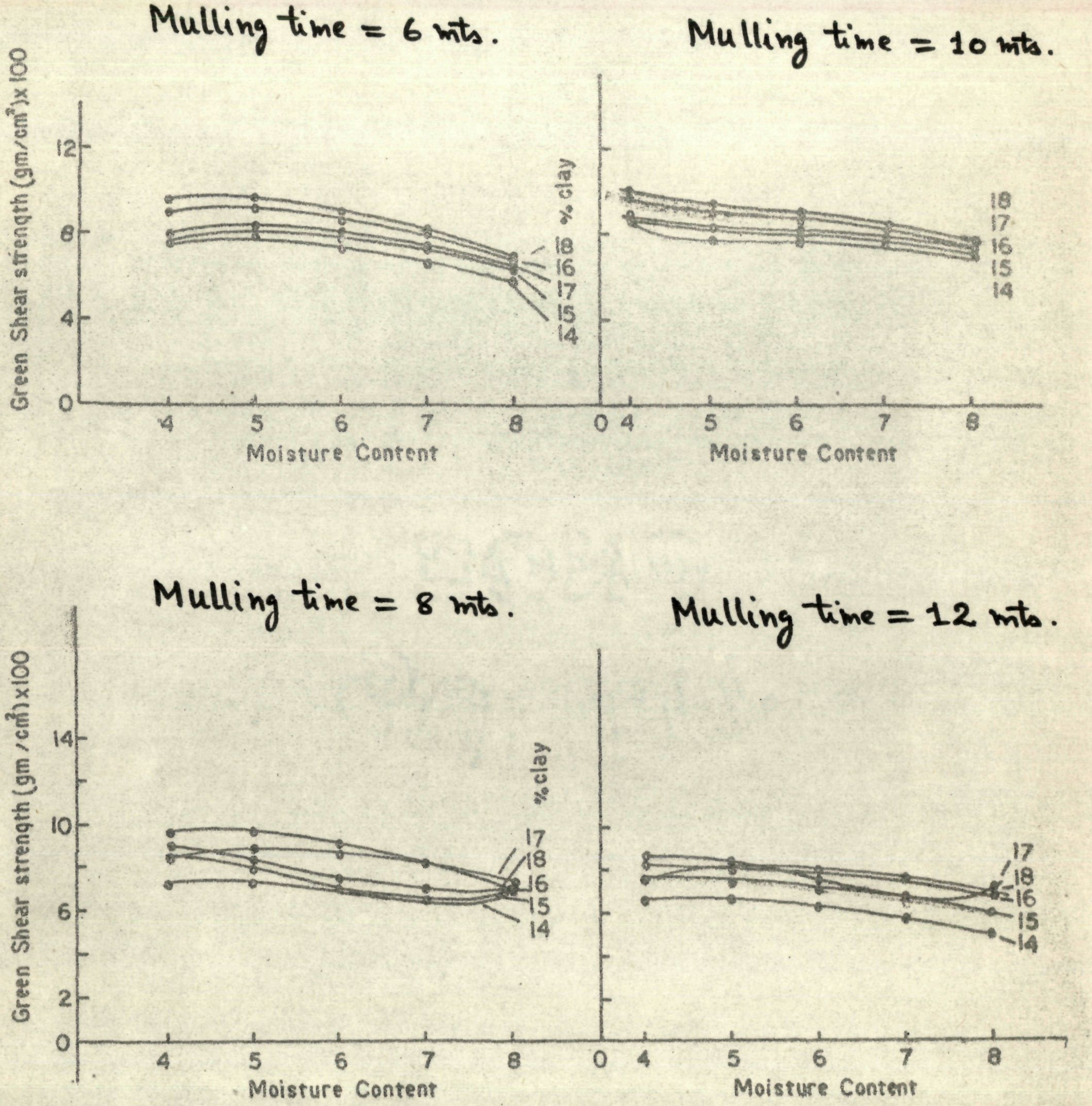


FIG: Variation of Green Shear strength with moisture content

(at different clay percentages)

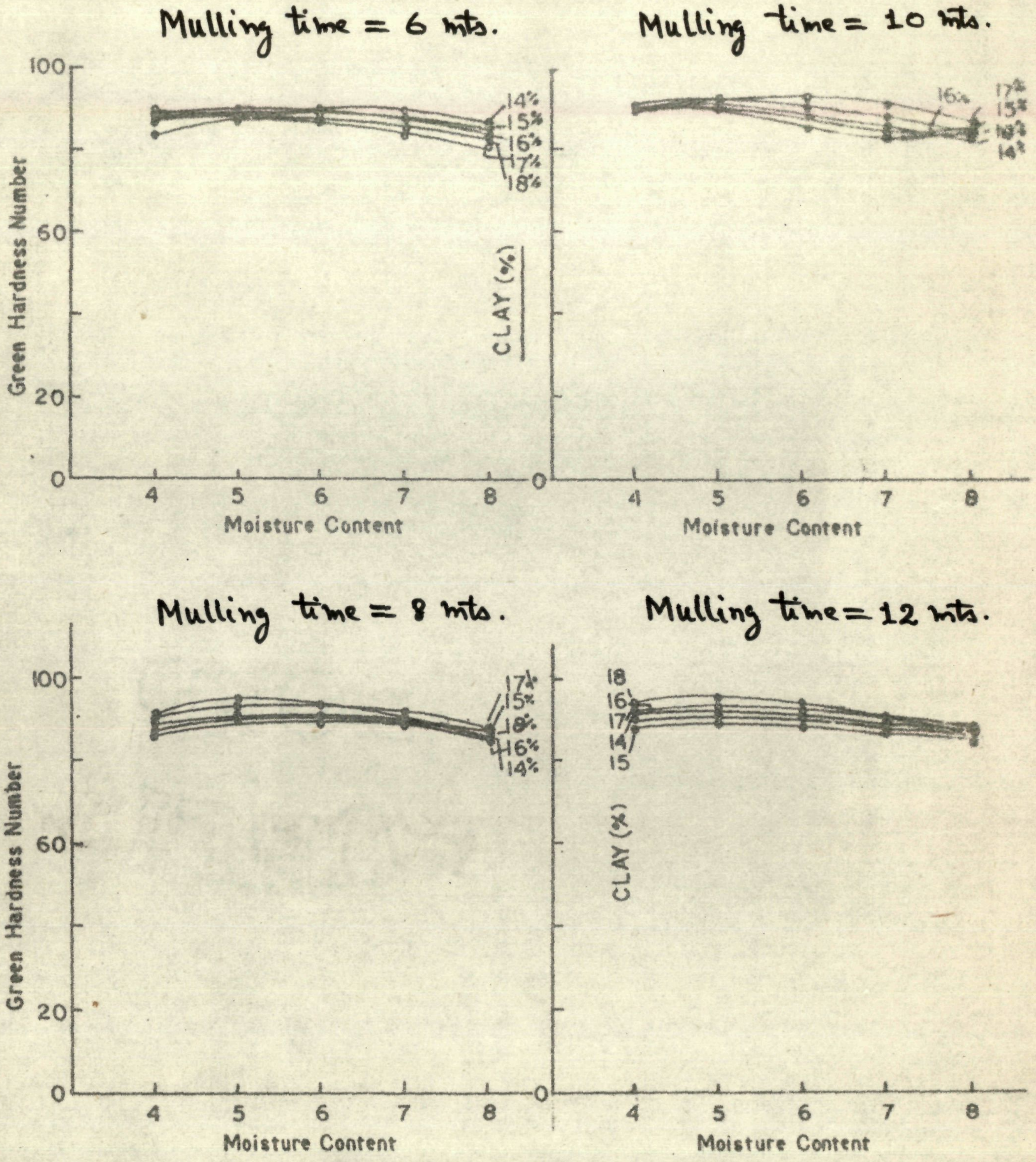


FIG: Variation of Green Hardness Number with moisture content.

(at different clay percentages)

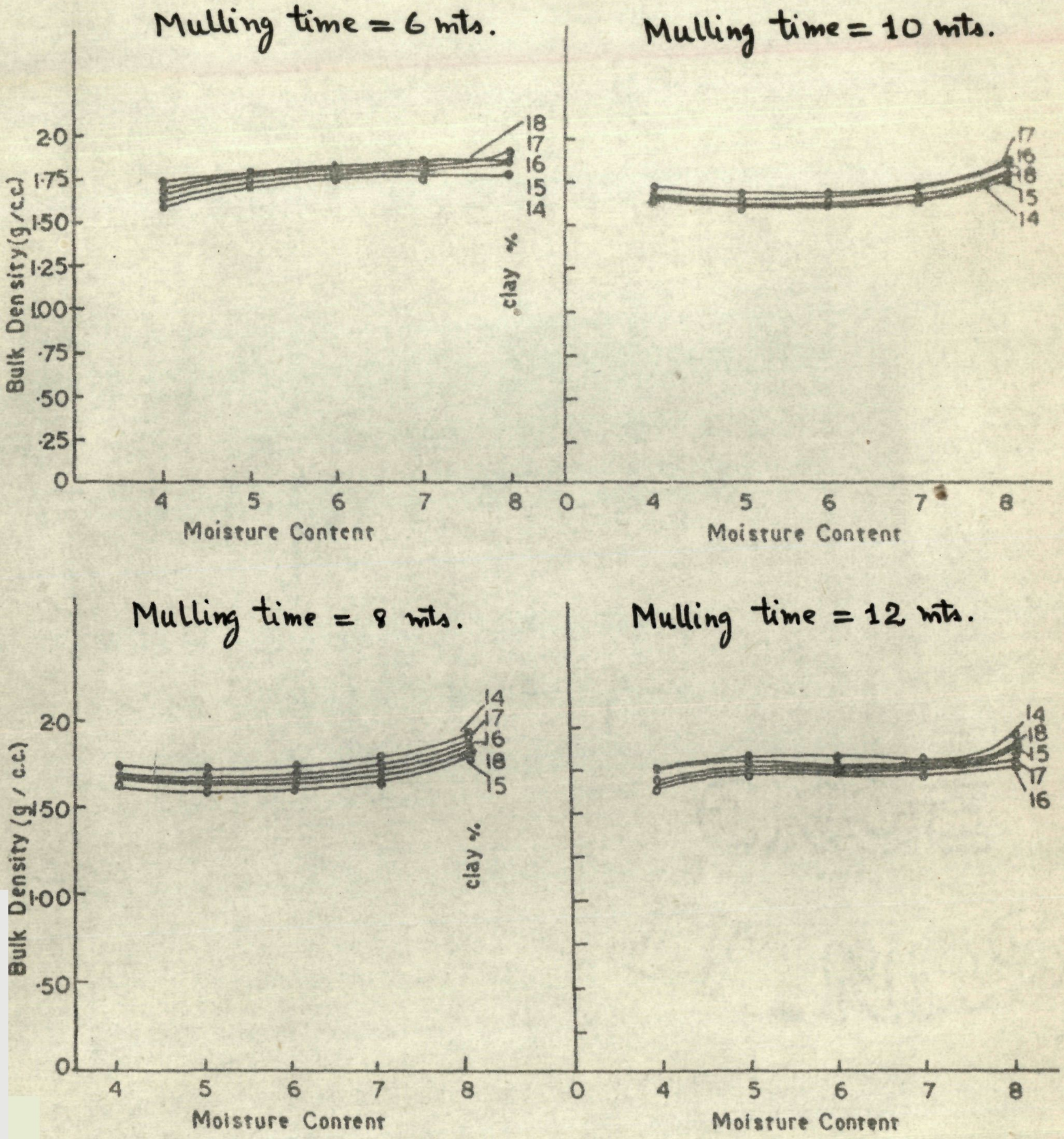
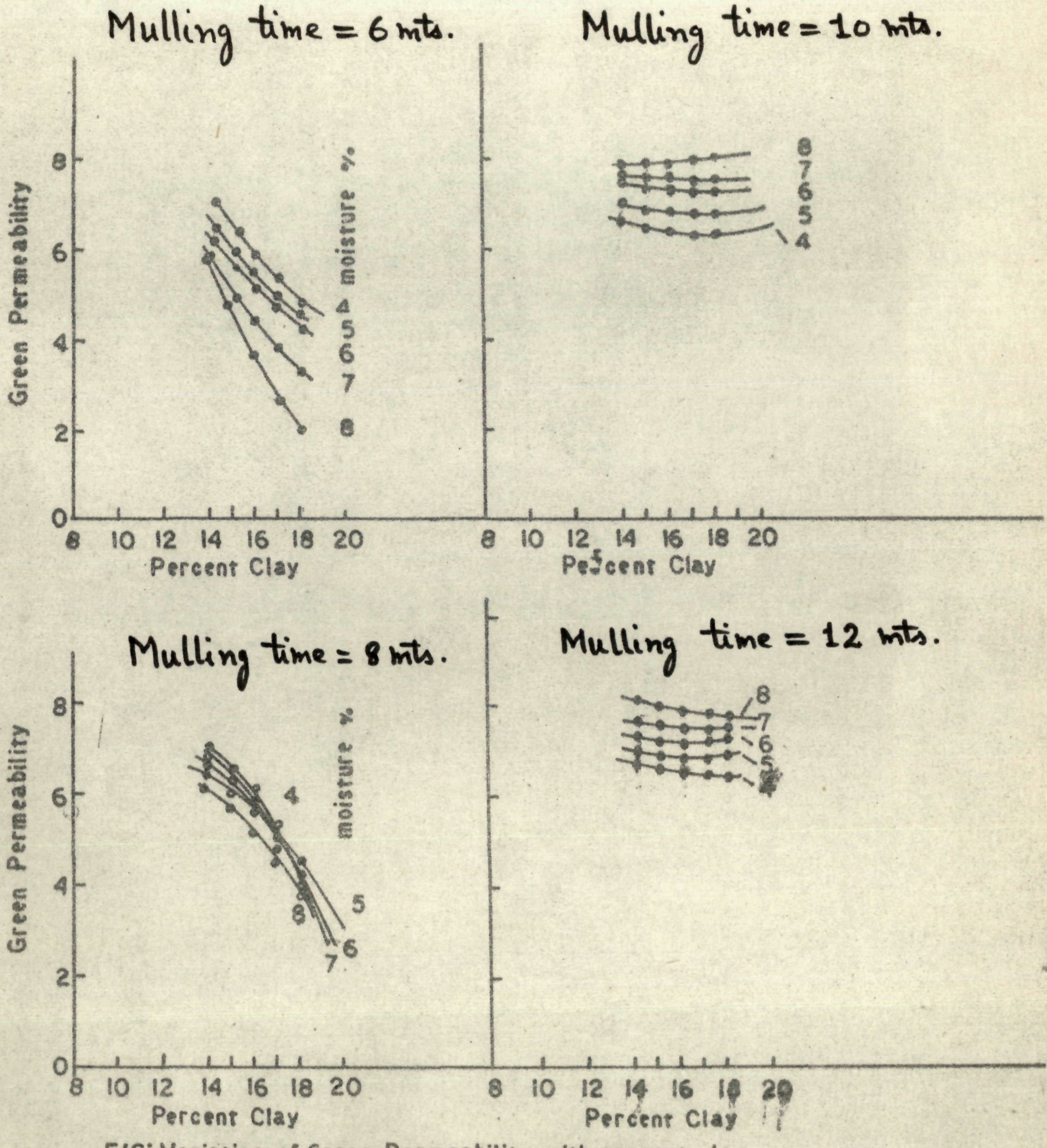


FIG1 Variation of Bulk Density with moisture content.

(at different clay percentages)



FIG; Variation of Green Permeability with percent clay

(at different moisture contents)

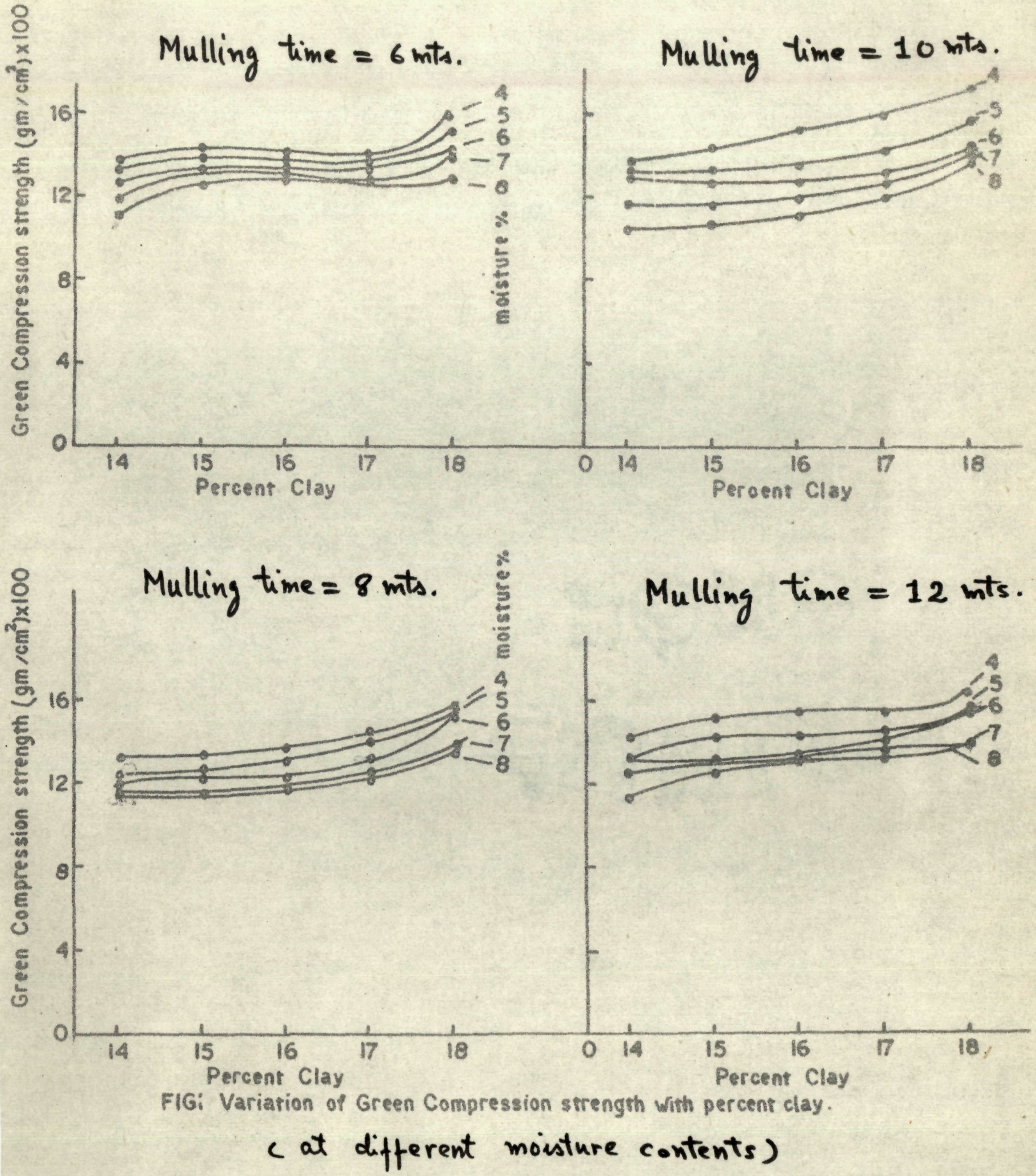


FIG: Variation of Green Compression strength with percent clay.

(at different moisture contents)

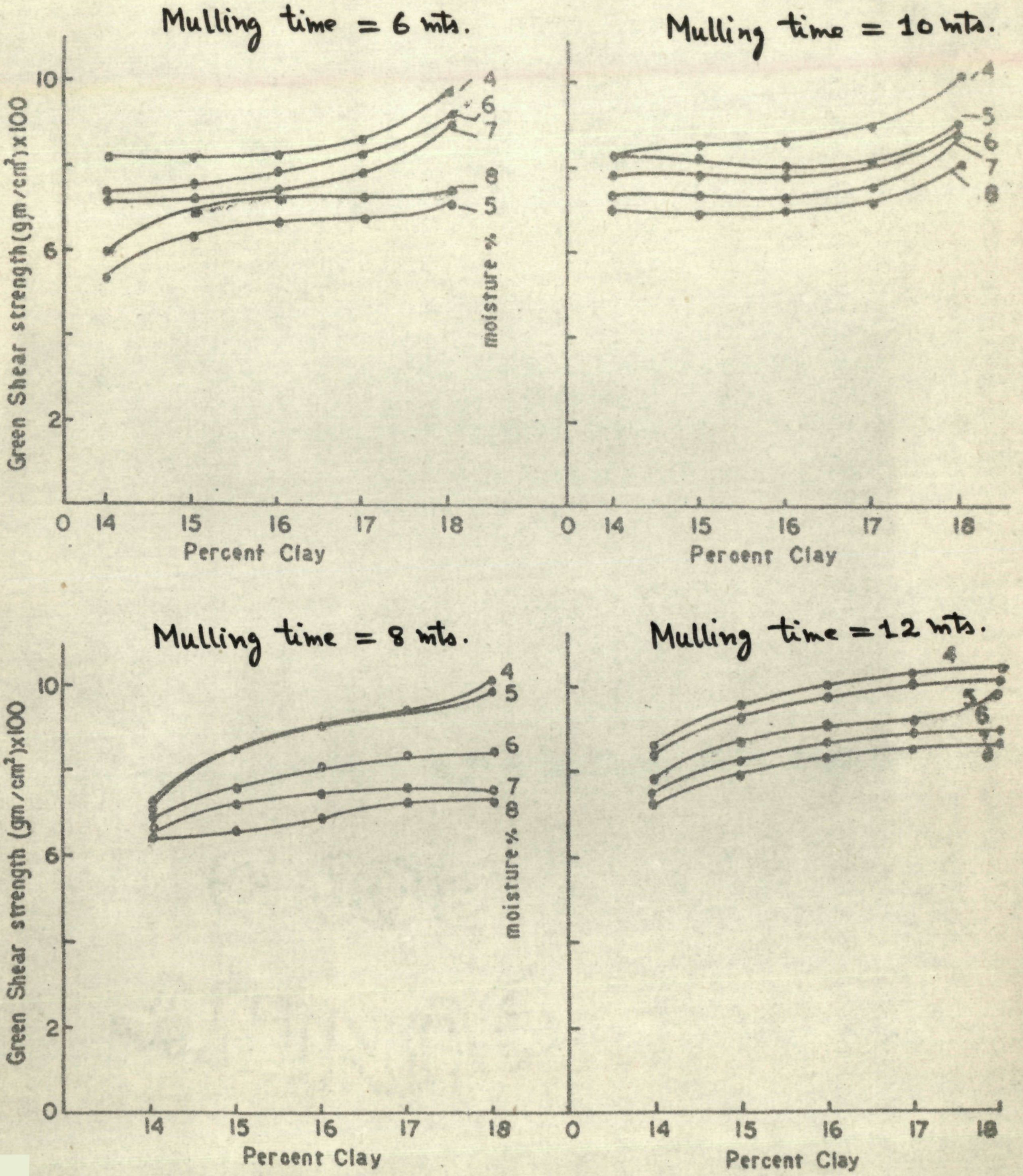


FIG: Variation of Green Shear strength with percent clay
(at different moisture contents)

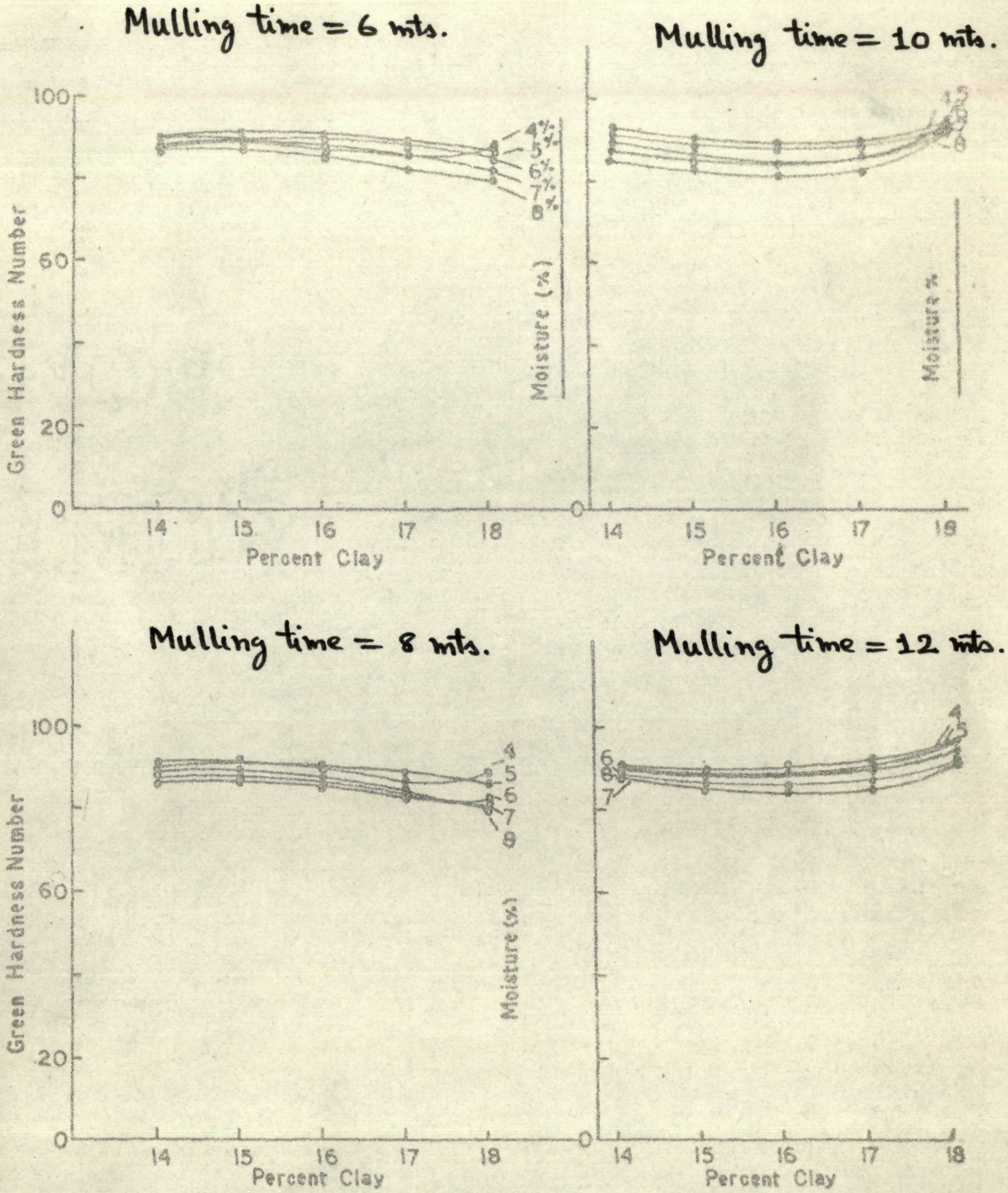


FIG: Variation of Green Hardness Number with Percent clay.

(at different moisture contents)

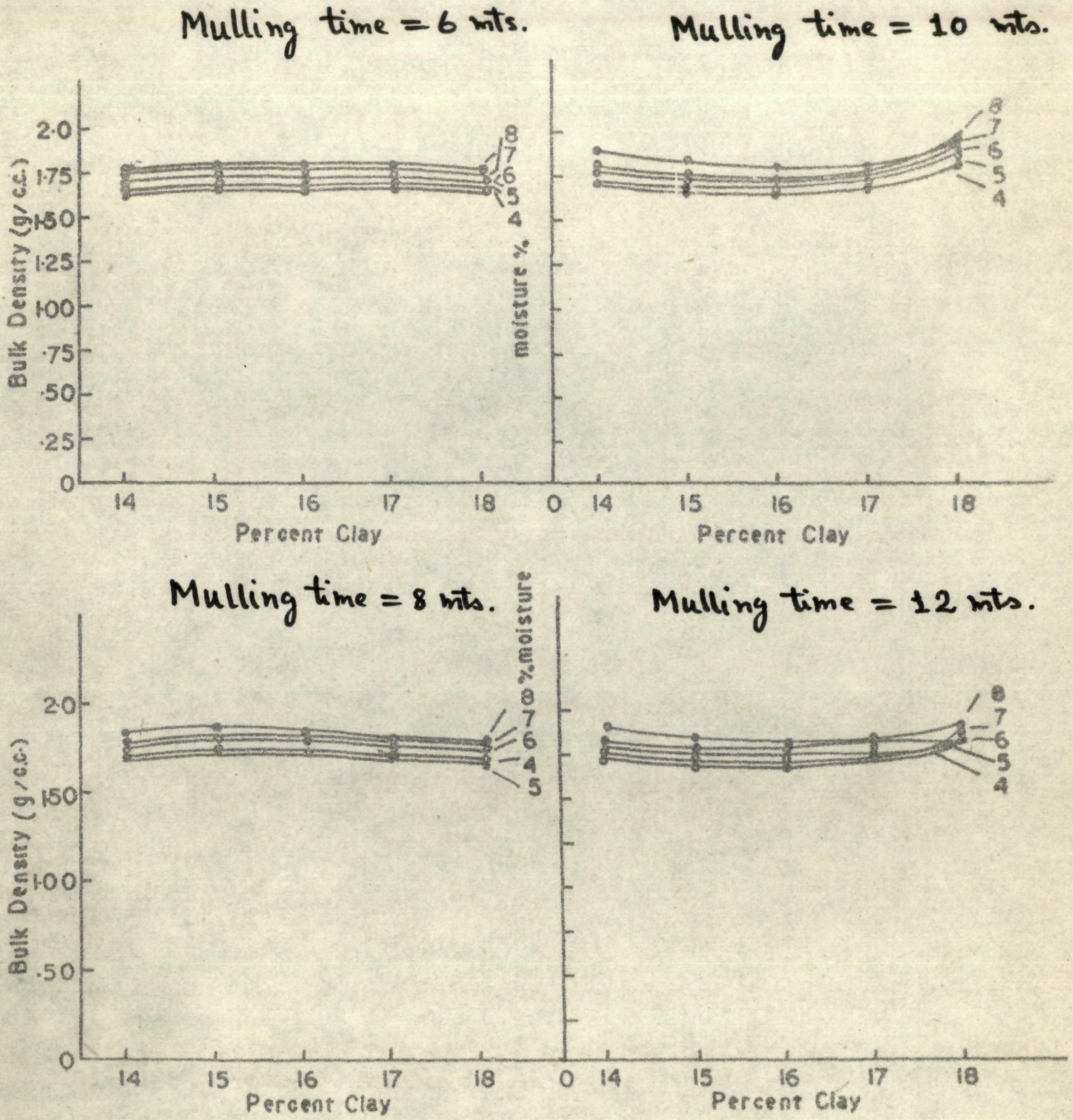


FIG: Variation of Bulk Density with percent clay.

(at different moisture contents)

Table - 5.1

Sieve Analysis of the silica sand used
(Mulling time = 6 mts.)

Sand Sample = 50gms

Sieve No.	Sieve opening mm.	Weight of Sand retained gm.	percent retained	Cumulative %cent retained
1.	1.40	0.00	0.00	0.00
2.	1.00	0.00	0.00	0.00
3.	0.63	0.143	0.286	0.286
4.	0.32	0.917	0.834	2.120
5.	0.20	7.657	15.314	17.434
6.	0.10	4.757	9.514	26.948
7.	0.06	31.271	62.542	89.490
8.	Pan	5.255	10.51	100.000
Total		50.000	100.00	

Table - 5.2

Sieve Analysis of the silica sand used
(Mulling time = 8 mts.)

Sand sample = 50gms

1.	1.40	0.00	0.00	0.00
2.	1.00	0.00	0.00	0.00
3.	0.63	0.055	0.11	0.11
4.	0.32	2.657	5.314	5.424
5.	0.20	6.410	12.82	18.244
6.	0.10	2.647	5.294	23.538
7.	0.06	30.186	60.372	83.910
8.	Pan	8.045	16.09	100.000
Total		50.000	100.00	

Table - 5.3

Sieve Analysis of silica sand used

(Mulling time = 10 mts.)

Sand Sample = 50 gms

Sieve No.	Sieve opening mm.	Weight of sand retained gm.	Percent retained	Cumulative percent retained
1.	1.40	0.00	0.00	0.00
2.	1.00	0.00	0.00	0.00
3.	0.63	0.139	0.278	0.278
4.	0.32	1.026	2.052	2.33
5.	0.20	9.52	19.04	21.37
6.	0.10	7.135	14.27	35.64
7.	0.06	25.68	51.36	87.00
8.	Pan	6.50	13.00	100.00
Total		50.00	100.00	

Table - 5.4

Sieve Analysis of the silica sand used

(Mulling time = 12mts.)

Sand sample = 50 gms.

1.	1.40	0.00	0.00	0.00
2.	1.00	0.00	0.00	0.00
3.	0.63	0.185	0.37	0.37
4.	0.32	3.16	6.32	6.69
5.	0.20	7.679	15.358	22.048
6.	0.10	6.647	13.294	35.342
7.	0.06	31.569	63.138	88.478
8.	Pan	5.761	11.522	100.000
Total		50.000	100.000	

Table - 5.5

(Mulling time = 6mts.)

Moisture content (%)	%clay 14%	%clay 15%	%clay 16%	%clay 17%	%clay 18%
	Green Permeability No.				
4.	7.2	6.1	5.2	5.4	5.0
5.	6.9	6.0	5.0	5.2	4.6
6.	6.3	5.5	4.8	4.7	4.2
7.	6.2	5.0	4.0	3.7	3.3
8.	6.1	4.9	3.8	2.1	0.9

(Mulling time = 8mts.)

4.	6.9	6.6	6.1	4.9	3.9
5.	6.9	6.6	6.2	5.1	4.2
6.	6.8	6.5	6.3	5.0	4.2
7.	6.5	6.5	5.7	4.9	4.5
8.	6.1	5.8	5.1	4.3	3.9

(Mulling time = 10mts.)

4.	6.5	6.0	5.2	5.2	4.9
5.	6.2	6.5	5.2	5.5	5.1
6	6.0	5.8	5.5	5.8	5.2
7	5.8	5.5	5.3	5.5	4.6
8	4.6	4.5	5.1	4.9	4.1

(Mulling time = 12mts.)

4	5.5	5.2	5.0	4.6	4.6
5	6.0	5.3	5.5	5.0	4.3
6	5.8	5.5	5.2	5.1	4.0
7	5.5	5.3	4.6	4.6	3.9
8.	5.2	5.0	4.4	4.0	3.2

Table - 5.6

(Mulling time - 6mts)

Moisture content %	Green compression strength (gm/Cm^2) x100				
	% Clay 14%	%clay 15%	%clay 16%	%clay 17%	%clay 18%
4	14.5	14.3	14.6	14.0	16.1
5	14.0	14.6	14.0	15.2	15.1
6	13.0	13.2	13.3	13.6	14.2
7	12.0	12.9	13.1	13.0	14.0
8	10.6	12.0	12.6	12.7	14.2

(Mulling time = 8mts.)

4	12.9	13.8	15.0	14.6	15.5
5	12.2	13.2	14.4	14.9	14.9
6	12.0	12.2	12.8	14.3	14.3
7	11.6	11.5	12.6	13.9	13.9
8	11.4	11.2	12.2	13.4	13.4

(Mulling time = 10 mts.)

4	13.9	14.6	15.4	15.8	16.6
5	13.5	14.4	13.6	14.5	14.8
6	12.6	13.6	12.4	14.1	14.3
7	11.8	12.4	11.9	13.2	14.0
8	10.3	11.7	11.7	12.9	13.8

(Mulling time = 12 mts.)

4	14.4	15.3	15.8	15.4	16.5
5	13.2	14.7	15.2	14.7	15.4
6	12.9	14.5	13.8	14.0	15.0
7	12.3	13.4	13.4	13.8	13.8
8	11.5	12.6	13.0	13.4	13.4

Table - 5.7

Moisture Content (%)	Green shear strength (gm/cm^2) x 100				
	% Clay 14%	% Clay 15%	% Clay 16%	% Clay 17%	% Clay 18%
(Mulling time = 6mts.)					
4	8.2	8.2	8.3	8.7	11.7
5	7.6	8.7	7.9	8.8	9.2
6	6.6	7.6	7.5	8.6	8.1
7	6.0	7.1	7.3	7.5	7.8
8	5.8	6.3	7.2	7.1	6.7
(Mulling time = 8mts.)					
4	7.7	8.4	9.1	8.2	10.5
5	7.3	8.0	8.3	9.0	9.5
6	7.1	7.2	7.5	8.6	8.6
7	6.9	6.7	7.4	7.6	7.8
8	6.7	6.6	7.2	7.4	7.5
(Mulling time = 10mts.)					
4	8.6	9.7	8.9	9.5	10.2
5	8.2	9.4	7.6	8.2	9.2
6	7.9	8.2	7.4	8.0	8.7
7	7.4	7.2	7.3	7.6	8.2
8	7.0	7.6	7.2	7.3	8.0
(Mulling time = 12mts.)					
4	8.7	9.5	10.1	10.2	10.5
5	8.4	9.3	9.4	10.0	10.2
6	8.1	9.1	8.9	9.3	9.8
7	7.8	8.6	8.5	8.5	9.1
8	7.5	8.0	8.0	9.3	8.8

Table - 5.8

Moisture content (%)	Green Hardness No. %Clay 14	%Clay 15	%Clay 16	%Clay 17	%Clay 18
(Mulling time = 6mts.)					
4	89	32	87	39	89
5	88	90	86	88	87
6	90	89	85	87	66
7	86	88	84	84	84
8	85	86	84	82	82
(Mulling time = 3mts.)					
4	91	92	90	88	87
5	89	91	86	89	88
6	88	89	88	90	89
7	87	86	85	90	90
8	86	90	84	88	86
(Mulling time = 10mts.)					
4	92	91	91	91	91
5	90	90	90	88	90
6	88	88	87	85	94
7	86	87	89	87	92
8	85	85	88	83	89
(Mulling time = 12mts.)					
4	90	89	92	93	94
5	89	88	90	91	91
6	88	88	89	90	90
7	87	86	88	89	89
8	87	85	87	88	88

Table - 5.9

Moisture Content (%)	Bulk Density (gm/c.c.)				
	%Clay 14	%Clay 15	%Clay 16	%Clay 17	%Clay 18
(Mulling time = 6mts.)					
4	1.68	1.65	1.71	1.73	1.61
5	1.69	1.68	1.73	1.78	1.68
6	1.73	1.73	1.78	1.80	1.76
7	1.78	1.76	1.83	1.83	1.83
8	1.81	1.77	1.85	1.88	1.93
(Mulling time = 8mts.)					
4	1.70	1.68	1.65	1.68	1.63
5	1.73	1.71	1.68	1.71	1.66
6	1.77	1.75	1.73	1.73	1.73
7	1.81	1.78	1.77	1.77	1.75
8	1.85	1.83	1.83	1.81	1.79
(Mulling time = 10mts.)					
4	1.66	1.63	1.65	1.65	1.63
5	1.70	1.67	1.68	1.67	1.67
6	1.73	1.75	1.71	1.70	1.69
7	1.76	1.77	1.75	1.73	1.73
8	1.79	1.81	1.79	1.78	1.80
(Mulling time = 12mts.)					
4	1.69	1.67	1.66	1.63	1.65
5	1.71	1.71	1.69	1.67	1.69
6	1.74	1.75	1.78	1.69	1.73
7	1.78	1.79	1.78	1.74	1.76
8	1.82	1.83	1.81	1.79	1.78

Table - 6.1

(Mulling time = 6mts.)

% Clay	Green permeability				
	Moisture content 4%	Moisture content 5%	Moisture content 6%	Moisture content 7%	Moisture content 8%
14	7.2	6.9	6.3	6.2	6.1
15	6.1	6.0	5.5	5.0	4.9
16	5.2	5.0	4.8	4.0	3.8
17	5.4	5.2	4.7	3.7	2.6
18	5.0	4.6	4.5	3.3	2.0
(Mulling time = 8mts.)					
14	6.9	6.9	6.8	6.5	6.1
15	6.6	6.6	6.3	6.5	5.8
16	6.1	6.2	6.3	5.7	5.1
17	4.9	4.3	5.0	4.9	4.3
18	3.9	4.2	4.2	4.5	3.9
(Mulling time = 10mts.)					
14	6.5	6.2	6.0	5.8	4.6
15	6.0	5.2	5.8	5.5	4.5
16	5.2	5.2	5.5	5.3	4.4
17	5.0	5.1	5.4	5.0	4.3
18	4.9	5.1	5.2	4.6	4.1
(Mulling time = 12mts.)					
14	5.5	6.5	5.8	5.5	5.2
15	5.2	5.3	5.5	5.0	5.0
16	5.0	4.7	5.2	4.6	4.4
17	4.8	4.4	5.1	4.4	4.0
18	4.6	4.3	4.0	4.1	3.2

Table - 6.2

(Mulling time = 6mts)

% Clay	Green compression strength (gm/cm^2) x 100				
	Moisture content 4%	Moisture content 5%	Moisture content 6%	Moisture content 7%	Moisture content 8%
14	14.5	14.0	11.5	10.9	10.6
15	14.3	14.6	13.2	12.9	12.0
16	14.6	14.0	13.3	13.1	12.8
17	14.0	15.2	13.6	13.0	12.7
18	16.1	15.1	14.5	14.0	12.8
(Mulling time = 8mts.)					
14	12.9	12.2	12.0	11.6	11.4
15	13.8	13.2	12.2	11.5	11.2
16	15.0	14.4	12.8	12.6	12.2
17	14.6	14.9	14.0	12.6	12.5
18	15.5	14.9	14.7	13.9	13.4
(Mulling time = 10mts.)					
14	13.9	13.5	12.6	11.8	10.3
15	14.6	14.4	13.6	12.4	11.7
16	15.4	13.6	12.4	11.9	11.7
17	15.8	14.5	14.1	13.2	12.9
18	16.6	14.8	14.3	14.0	13.8
(Mulling time - 12 mts.)					
14	14.4	13.2	12.9	12.3	11.5
15	15.3	14.7	14.5	13.4	12.6
16	15.8	15.2	13.8	13.4	13.0
17	15.4	14.7	14.0	13.8	13.4
18	16.5	15.4	15.0	13.8	13.4

Table - 6.3

(Mulling time = 6 mts.)

% Clay	Green shear strength (gm/cm^2) x100				
	Moisture content 4%	Moisture content 5%	Moisture content 6%	Moisture content 7%	Moisture content 8%
14	8.2	7.6	6.6	6.0	5.8
15	8.2	8.7	7.6	7.1	6.3
16	8.3	7.9	7.5	7.3	7.2
17	8.7	8.8	8.6	7.5	7.1
18	11.7	9.2	8.1	7.8	6.7
(Mulling time = 8mts.)					
14	7.7	7.3	7.1	6.9	6.7
15	8.4	8.0	7.2	6.7	6.6
16	9.1	8.3	7.5	7.4	7.2
17	8.2	9.0	8.6	7.6	7.4
18	10.5	9.5	8.6	7.8	7.5
(Mulling time = 10 mts.)					
14	8.6	8.2	7.9	7.4	7.0
15	9.7	9.4	8.2	7.8	7.6
16	8.9	7.6	7.4	7.3	7.2
17	9.5	8.2	8.0	7.6	7.3
18	10.2	9.2	8.7	8.2	8.0
(mulling time = 12 mts.)					
14	8.7	8.4	8.1	7.8	7.5
15	9.5	9.3	9.1	8.6	8.0
16	10.1	9.4	8.9	8.5	8.0
17	10.2	10.0	9.3	8.5	9.3
18	10.5	10.2	9.8	9.1	8.8

Table - 6.4

(Mulling time = 6 mts.)

% clay	Green Hardness No.				
	Moisture content 4%	Moisture content 5%	Moisture content 6%	Moisture content 7%	Moisture content 8%
14	89	90	90	83	87
15	88	90	89	88	86
16	85	89	89	87	84
17	89	88	86	84	82
18	89	88	86	84	82
(Mulling time = 8 mts.)					
14	91	89	88	87	86
15	92	91	87	86	85
16	90	86	85	85	84
17	88	89	85	82	82
18	87	88	82	81	80
(Mulling time = 10 mts.)					
14	92	90	88	86	85
15	91	90	88	87	85
16	91	90	87	89	88
17	91	[illegible]	85	77	83
18	91	90	94	92	89
(Mulling time = 12 mts.)					
14	90	89	88	87	87
15	89	88	88	86	85
16	92	90	89	88	87
17	93	91	90	89	88
18	94	91	90	89	88

Table - 6.5

(Mulling time = 6mts.)

% Clay	Bulk Density (gm/c.c.)				
	Moisture content 4%	Moisture content 5%	Moisture content 6%	Moisture content 7%	Moisture content 8%
14	1.68	1.69	1.73	1.78	1.81
15	1.65	1.68	1.73	1.76	1.77
16	1.71	1.73	1.78	1.83	1.85
17	1.73	1.78	1.85	1.83	1.88
18	1.80	1.85	1.90	1.83	1.93

(Mulling time = 8mts.)

14	1.70	1.73	1.77	1.81	1.85
15	1.68	1.71	1.75	1.78	1.83
16	1.65	1.68	1.73	1.77	1.83
17	1.68	1.71	1.73	1.77	1.88
18	1.73	1.76	1.73	1.80	1.85

(Mulling time = 10mts.)

14	1.66	1.70	1.73	1.76	1.79
15	1.66	1.67	1.71	1.79	1.81
16	1.65	1.68	1.71	1.75	1.79
17	1.65	1.67	1.74	1.78	1.78
18	1.63	1.67	1.69	1.73	1.80

(Mulling time = 12mts.)

14	1.69	1.71	1.74	1.78	1.82
15	1.67	1.69	1.73	1.79	1.82
16	1.66	1.68	1.73	1.78	1.80
17	1.65	1.67	1.68	1.74	1.79
18	1.65	1.69	1.73	1.76	1.78

CHAPTER - III

SOUNDNESS OF CASTINGS

Metallurgically an ideal casting is that which possesses optimum properties and is produced with the highest casting yield. The casting yield is defined as the percent ratio of the weight of the finished product to the weight of the poured casting. It is impossible to obtain 100% casting yield, as some metal must be used for the gating and feeding systems; often also for trimming or machining. Some of the casting surfaces. The production casting yield is the ratio of the total weight of finished castings of required acceptable properties to the total weight of metal melted. The production yield is usually smaller than the casting yield, because of the inevitable production of some casting the properties of which fall outside the acceptance limit. Metallurgically important properties of finished castings could be described as

1. Surface
2. Size
3. Structure
4. Soundness and
5. stress.

Casting quality depends on the optimum being obtained in one or more or all of these properties and variations from the optimum are related directly to some aspects of metal or mould behaveour and indirectly to to the numerous process variables.

3.1 Criterion of soundness :

American Foundrymen's Society (8) proposed several tests to evaluate soundness such as casting defects test i.e. blows, pinholes, drop, dirt, cuts and washes, crabs, rattails, buckle, shrinks, metal penetration, mould crack. The most commonly used method is the method of finding blowholes and pinholes etc. through X-ray technique. Inspection comprises those operations which the quality of th the casting and result in rejection of unsatisfactory ones. Inspection procedures may be classed as follows :

1. Visual, surface inspection for foundry defects.
2. Dimensional , requiring gauges for measurements.
3. Metallurgical, requiring chemical , physical and mechanical properties.

Tensile testing is more widely used than any other method of testing owing to the general importance of strength properties in engineering.

While composition standards establish the basic chemical identity of an alloys , and hence different properties, can be obtained in castings made in an alloy of the same composition. Furthermore such properties can be affected by structural features, such as cavities, which are partly independent of the composition. It is therefore essential to carryout various property tests. Test bars of various designs, and cast by various methods, either serve to establish specific and fundamental property values of cast metals, such as mechanical and physical properties. Test bars used for evaluation of fundamental cast metal properties can be cast in a foundry and the designs, methods and casting techniques used vary with the specific objectives of the tests.

Standard specification test bars used for evaluation of specified mechanical or physical property standards, may supplement or even replace the chemical composition acceptance tests. From the production and industrial point of view, tensile test bar practice fulfils an obvious practical need, not only in providing data on mechanical properties of cast metals.

In addition to the tensile test bar properties, other mechanical properties, such as hardness can be tested to obtain fundamental data. Hardness is a localised surface test. Depending on the geometry of the inden for the area affected by identification may even be within a single grain in the structure. A hardness test can be used to measure the average hardness of the structure or a particular hardness of a single constituent or even parts of it, as grain boundries (Micro-hardness). As hardness is a measure of elastic and strain hardening phenomena of the structure, its application is mainly for testing either the structural condition of a given component or theuniformity of the structure over component as a whole. in a sense hardness provides informationss similar to the microscopic examination except that the hardness test is more direct and quick and takes into account a number of lattice and grain imperfactions.

Casting density takes case of internal defects such as blowhole, pinholes etc. In many cases intricately cored castings are extremely difficult to measure accurately particularly the internal sections. It is important for three main reasons to ensure that these sections are correct in thickness :

1. There should be no additional weight which would make the finished product heavier than permissible,
2. Sections must not be thinner than designed in case of detracting from the strength of the casting;
3. If hollow cavities have been reduced in area by increasing the metal thickness of the sections any flow of liquid or gases intended by the designer is reduced.

Murthy (9) has used casting density and ductility of casting as a soundness parameter in his studies on SG 70 aluminium alloy.

Ananthanarayanan (10) has used ultrasonic examinations of aluminium alloys LM25(7%si, 0.3% Mg) and LM16(5%si, 1.5%cu, 0.5% Mg) as a soundness parameter.

Lal & Shukla (4) has studied the aluminium specimens upto a strain rates of 1, 100 sec^{-1} as a soundness parameters.

3.2 Defects in Castings and their remedies :

Several defects are produced during sand casting. Due to defective sands castings, the total output is decreased by 5 to 10 percent. It is, therefore, necessary to understand the various causes which are responsible for the occurrence of casting defects so that suitable remedies may be applied to eliminate the defects. The type of defects which can sometimes be definitely related to moulding sands have been discussed by Heine and Rosenthal (6).

Blows :

Blows are baloon - shaped gas cavities at or below the casting surface caused by mould gases and pressure. They are usually remedied by reducing the amount of gas formed by the mould or improving its permeability.

Pinholes :

Pinholes appear as numerous small gas cavities at or only slightly below the surface. Excessive moisture and poor permeability can cause pinholes.

Hein and Rosenthal (6) has concluded that in aluminium alloys containing more than about 1 percent magnesium, a reaction tends to occur between the magnesium of the alloy and water vapour of the mould. Hydrogen filled pinholes at the surface are the result.

Drops :

This defect is usually due to weak sand or rough mould handling. A portion of the cope drops into the drag Remedies consists of bonding the sand to higher strength, moulding to greater hardness, better sand mixing or some other means of strengthening the sand.

Dirt, cuts, and Washes : Dirt , cuts and washes are due to weak sand , especially if low in dry strength or with insufficient tempering water, encourages dirt formation. Careless moulding may also permit dirt in the mould. Remedies for these defects consists of raising the green strength, and raising the air set and dry compression strength to over 20psi; improved moulding pattern etc.

Scabs :

They are caused by a portion of the mould surface spalling or flaking off because of thermal expansion of the sand. Elimination of scabs require greater thermal stability of the sand. Remedies consists of softer ramming of mould, reduction of dry strength, use of combustibles or cushioning agents in the sand, better mixing etc.

Rattails :

These defects appear as streaks or slight ridges chiefly on large flat surfaces and are sand expansion type defects. They indicates the first stage of scabbing. Rattailing is reduced by a lowering of hot strength through the use of 0.5 to 2.0 percent wood flour, bentonite 3 to 6 percent, sea coal, minimum moisture content, softer ramming and other procedures which make the mould surface more stable.

Buckle :

This defect is similar to the rattail. However it appear as a V grove while rattails show on surface adjacent to the defect raised with respect to the other surface.

Shrinks :

Certain shrinkage defects are related to sand conditions. These are really apparent shrinks since they are caused not by metal shrinkage but by enlargement of the mould cavity after the casting has been poured. The sand may be too soft and metallostatic pressure causes mould - cavity, enlargement or it may not be thermally stable. The casting shows some enlarged dimensions or is over weight when this defect occurs. Where the casting is obviously bulged or oversize, the defect of mould enlargement is called a "swell".

Metal Penetration :

This defect consists of a spongy mass of sand and metal which adheres tightly to the casting. Metal may penetrate the sand because it is mechanically soft and porous or because of chemical reaction between the metal and sand causing wetting of the sand grains by the metal. Some of the remedies employed are harder ramming , improved sand flowability, use of mould coating and the use of special facing sands.

Mould Crack :

If the mould is not strong enoughor no t properly supported it may crack. Metal can run into the crack and appear as a fin on the casting.

Defects in Aluminium castings

The main difficulties in the aluminium melting practice.

1. Drossing

2. Gas absorption

Drossing :

Drossing is the formation of aluminium oxide and other oxides which get collected on the melt surface. Aluminium alloys easily react with water vapour, and other combustion products. Thus , dross formation can be minimized if the charge is protected from combustion products and the melting process is rapid. Separation of dross from the molten metal depends on the difference in their specific gravities. In case of aluminium, however, the specific gravity difference is very small and separation of dross is not easy. The oxide film mixes with the alloys and forms aluminium oxide inclusions, thus causing a serious detrioration in casting quality. Gas

Gas absorption :

Aluminium alloys readily absorb hydrogen, and as the solubility for hydrogen increases rapidly with temperature, the molten metal should not be taken much above 700°C. Hydrogen is derived from the products of combustion and water vapour in the furnace atmosphere. Gas porosity in aluminium castings is due to hydrogen which is taken into solution in the metal while it is molten and is rejected as the metal cools.

Removal of difficulties :

The above difficulties are removed by fluxing and flushing . Gaseous fluxes used to purge the metal include nitrogen, helium, argon and chlorine. The effect of chlorine is very powerful when it is blown through the alloy. ammonium chloride and hydrogen chloride vapour are formed which carry away bubbles of hydrogen and oxides from the alloy.

Gas elimination by chlorine is carried out by slowly bubbling the gas through the so that there is a large surface area of contact between the chlorine and the molten metal. Inert gases do not react chemically and only carry away the oxides to the surface of the metal. Flushing is carried out by skimming off surface dross and then bubbling the dry gas through the melt for ten minutes. It is done at a temperature below 700°C to obtain maximum hydrogen removal.

3.3 Methods of Inspection and testing

Production methods must be supervised and casting checked in each stage of manufacture. The finished casting before being released from the foundry , must be approved and passed as meeting the requirements of the customer's drawing and specification. Firstly, the casting must be sound and free from surface defects. Metal thickness must be maintained in order to that after machining the casting will meet dimensional requirements.

The various methods of testing casting are as follows :

1) Weight or Displacement testing :

Casting density testing is carried out by accurately wighing each casting or by measuring the displacement caused by immersing the casting in a suitably filled measuring Jar or Vessel. Casting weight is divided by displacement volumes, it gives the casting density. In certain instances where extreme accuracy is demanded from the founder, a tolerance of plus or minus one percent of a given weight only is allowed as is cited by Kondie (13).

2) Radiographic method :

Radiographycan be utilised so for inspecting casting for any metal; the technique are not materially different from those in medical investigations. Radient energy from an X-ray tube, capsule of radium sulfate (radium or gamma-ray radiography),or radioactive cobalt is passed through the casting, or section of the casting, and recorded on a film held against the opposite surface. Defects in the form of cracks or voids are recorded as blackened areas on the film, since the radiant energy moves more easily through the less dense region. Some defects readily disclosed by radiographic inspection are sand spots, cracks, internal and external hot tears, unfused chills and chaplets, shrinkage, and surface gas or pin hole porosity in short, any discontinuity or collection of discontinuites exceeding about 2 to 3 %cent. of the casting thickness, has concluded by Heine & Rosenthal (6).

3. Magnetic and fluresecent powder inspection :

In the former magnetic powder is either dusted over the surface of a magnetised casting or flowed over it in an oil suspension. Powder particles collect at any crack or discontinuity in or near the surface; opposing free surfaces of the defect act as north and south poles. The whole casting may be magnetised, if enough current is available, or prods may be used to instpect small areas of large castings.

Castings of non-magnetic materials may be immersed in a warm suspension of fluorescent powder in penetrating oil; the suspension penetrates even minute cracks and pores. The use of ultraviolet light is thus obviated, but defective areas are some what less readily seen. Magnetic powder inspection is useful for detecting discontinuities at and slightly below the surface. It can be used only on ferrous materials. Fluresoent powder inspection can be used on all materials, but detects only surface defects.

4. Ultrasonic reflectoscope :

The ultrasonic reflectoscope is sometimes used as cracks and shrinkage cavities in large castings. A flat surface is prepared on the casting against which a quartz crystal is pressed; a thin film of oil insures good contact. Ultrasonic vibrations are sent through the crystal, and their reflections from any free surface are picked up andrecorded on an oscilloscope. The position of the defect within the casting can be found accurately by a calibrated scaling system on the oscilloscope.

5. Dimensional Control : It is nearly always required; some times it is an extremely critical requirement. Initial casting from a new pattern are usually carefully measured in a layout room to be sure the casting conforms to blueprint specifications. After castings are found to be consistently within tolerances, spot checks suffice for production control. Often elaborate gages are specially contracted to permit a rapid check of particular casting dimensions, during a production run.

6. Smooth surface finish :

It is always a desirable character-stic and is some times a field requirement. It is described by a "Number" which is an average of the height of thepeaks (and depths of the valleys) on a casting surface. The number may be a simple " arithmetical" average or it may be a "root mean square" average.

Heine and RoSenthal (6) has concluded that casting surface finishes vary from about 90 microinches for smooth plaster moulded castings to over 300 microinches for heavy castings made in coarse sand. The degree of surface roughness on as cast surface is determined by visual comparison with cast standard, or by use of a direct reaching surface roughness indicator (profilometer). In the later case a stylus is drawn carefully over the surface an electronic pickup translates the signal from the sy stylus into an average surface roughness reading. Visual comparison (with a standard) in an adequate quality - control check for most sand castings but very smooth-surfaced sand castings and plaster or investment casting requir the use of an automatic indicator to accurately gauge surface quality.

Casting Surface hardness and tensile strength testing :

Brinell Hardness test :

Thistest consists in forcing a steel ball of diameter D under a load P into the test piece and measuring the mean diameter of the indentation left in the surfaces after removal of the load. This Brinell hardness is obtained by dividing the test load p by curved area of the indentation. This curved surface is assumed to be portion of the sphere of diameter D.

The Brinell hardness number is given by :

$$BHN = \frac{p}{A}$$

Where p = Load in Kg

A = area of contact between the ball and the indentation, in mm^2.

Then the surface area of indentation

$$= \frac{\pi D}{2} \left(D - \sqrt{(D^2 - d^2)} \right)$$

$$\text{Brinell hardness No.} = \frac{2p}{\pi D \left(D - \sqrt{(D^2 - d^2)} \right)}$$

Test requirements :

1. Ball : Diameter of the ball = 10mm $\pm$ 0.0045mm

The ball should be of hardened and tempered steel with a hardness of atleast 850VHN. It should polished and free from surface defects. For aluminium and brass, a maximum load, p = 750 Kgf

2. Test piece :

Thickness of thetest piece should not be less than 8 times the depth of identation. The test surface should be free from oxide film.

3. Load : Applied load

$$p = 30 \times D^2$$

where D = diameter of the ball in mm.

4. Diameter of identation should be measured in two directions normal to each other with an accuracy of $\pm$ 0.25% dameter of ball, under microscope provided wbth cross table and calibrated measuring screws.

Tensile Test :

The tensile test of ductile materials gives the tensile properties like tensile strength, yield point, proportional limit, elongation and reduction of area. It is widely applied in the design of materials for structural and general engineering purposes. During a tensile test, the speci-men is subjected to gradually increasing tensile pull untill it breaks.

The machine used for tensile test consist essentially of a device for applying a steadily increasing load to a test piece of metal, The device for applying the load are usually ofa a hydraulic type. The load is indicated on a calibrated dial. The material specimen is firmly held in the grips of the testing machine without slippage when the load is applied.

I. S. I. (II) has recommended several test rods.

Gauge length l = 5.65

for short rods according to I.S.I.

L_0 = 5.65 x 5

= 27.25m.m.

= 11.3

= 11.3 x 5

= 56.5 mm.

3.4 Factors effecting soundness

3.4.1 Solidification characteristics of metal being cast :

Shrinkage : During solidification , a number of important changes are occuring which have a bearing on the soundness of the casting.

First of all, metals contract :

1. On cooling in the liquid state.

2. On transforming from the liquid to the solid state.
3. on cooling in the solid state.
In a single casting , all three of these contractions. may be occuring simultaneously , although the usual case is for the liquid metal to be uniformly at the freezing temperature while solidification occurs. This is because the latent heat of freezing tends to smooth out temperature variations that are normally present in the casting during cooling. These

contraction effects have to be allowed for in designing the casting and its feeding system.

Freezing - temperature Range :

Another important fact for consideration is that many alloys freeze over a temperature range rather than at constant temperature. This means that solid and liquid metal can both be present in a given part of the casting. What actually happens is that the metal starts to freeze on the outside as the freezing progresses inward. However, not all the liquid metal available near the outside freezes immediately, so that liquid metal is still present there, even though partial solidification may have progressed close to the centre of the casting as is mentioned by Steinbauer (12). The freezing mechanism may be though of as a wave like progression of two advancing fronts, one representing the begining of freezing and the other the end of freezing. The spread between these fronts is affected greately by cooling rate and alloy composition. Thus, for pure metals the two fronts merge and a skin of metal , presenting as essentially smooth interface to the liquid, grows as freezing progresses. Further more, the solid metal forms as a aping treelike growth, not unlike a fir tree in appearance has studied by Steinbauer (12) This so called dendritic structure provides the possibility for entrapping small volumes of liquid metal that can not be properly fed from the interior. When these isolated patches of liquid metal contract on freezing, a void is created. Thus a generalised porosity may occur unless the casting is designed to provide liquid metal to fill these voids. The specific gravity of the metal is also a factor here, for those metals of higher specific gravity, like steel or brass, develop a much greater pressure head at a given height than light metals like aluminium or magnesium, making it easier to feed the casting.

General Freezing Behaviour :

Because solidification progresses from the outside to the centre of the casting. ~~Progressive solidification~~ this manner of freezing has been reffered to as progressive solidification. Unfortunately, the term has also been used with refrence to the proportioning and feeding of castings so that section most distant from the metal supply will freeze first, with solidification progressing in a uniform manner toward the riser or heads which serves to furnish the necessary feed metal as shrinkage takesplace.

Directional Solidification :

The only way in which development of voids due to metal shrinkage during solidification can be prevented is by providing the constant supply of extra liquid metal for thispurpose. Thus if a casting is so proportional and disposed with respect to the feeding system that the sections most distant from the available liquid metal will solidify first, there will be a successive feeding of the contracting metal by still liquid metal until the heaviest and last to freeze section is reached. This in turn can be fed by extra reservoirs of metal provided for that purpose and referred to as riser or heads. These risers or heads are attached to the casting at the right locations and in a manner such that they can continually supply hot liquid metal to the shrinkage casting until it is completely solidified.

The solidification characteristics of casting alloys must be understood by designers to assure the proper feeding of casting and to avoid defects that occur if this fundamental behaviour of metals goes unrecognised. Undesireable shrinkage areas , cracks, corner defects, mass effects, warpage etc. are factors that can be corrected by proper design.

3.4.2 Pouring Temperature :

Metals that is too cold will only result in incompletely filled moulds (misruns) or cold shuts (lack of fusion between several portions of metal entering a mould), but may form ladd skulls , as well i.e. a portion of the metal will solidify in the ladle which renders the ladle unfir for further use untill the metal is removed. If the temperature is too high, the metal may penetrate the sand , cause fusion of the sand, create excessive porosity absorb too much gas, or give a coarse grain structure to the metal. Accurate temperature measurement of the metal entering a mould , coupled with close observation results , is a practice that is used to furnish information establishing the proper pouring temperature range for each casting.

The melting point of Aluminium is $658^{o}C$, while that of Aluminium Silicon hardner is about $640^{0}C$. Pyrometeic control is escential in aluminium melting. Suitable casting temperature for a particular design of casting should be cast, as for as possible, at the lowest temperature at which the section can be run, allowing air bubbles and dross to escape, because rapid solidification gives strong and sound aluminium casting.

Konadic (13) has shown that tensile strength increases with increase in pouring temperature, reached maximum and consiquently decreases with further increase in pouring temperature and attains a minimum value.

3.4.3 Design of Castings :

Sometimes there is only one design which will perform the service intended by the designer. In this case, the foundryman may be required to use all the techniqwe -cal abilities available to produce the casting as it is, whether the design is a favourable or an unfavourable one for foundry practices. It is of course a unique advantage of the casting process that any intricate shape may be cast. Often, however, several designs are possible and one of these may be especially suited to the casting process. In many cases, it is possible for the designer to alter thestructural characterstics of the part so that a better or more economical casting may be produced without interfering with functioning of the part. The later situation is one which is most advantageous to all, the designer, user and the foundryman. Characterstics of minimum section thickness , dimensioned, accuracy, various allowances needed , proper webbing, limiting shapes for soundness and many other factors of the various casting processes need to be known to the designer. Then he can design the casting so that it will perform its functional requirements and still be a part that can be economically and favourably cost.

Mechanical Strength :

On a drawing board, the sections of a casting are assu assumed to be of metal uniformly sound, homogeneous, and havin having a certain mechanical strength. Stress calculations and most experimentally determined stresses in casting are made with the same assumptions. The factual relation between these assumptions and practical castings depends greatly on the casting design, foundry practices, and the nature of the alloy. Accuracy of

Accuracy of Mechanical Property information :

Assuming the metal is sound, accurate knowledge of its mechanical properties is needed before the casting can be designed for strength. Mechanical properties such as tensile , yield, compressive, torsional, shear, and impact strength, endurance; limit notch sensitivity; creep characteristics; hardness; elevared; temperature strength; and modulus of elasticity or rigidity all need to have quantitative values for the casting alloys if designers are to employ calculations and empirical design formulas.

Metal Soundness and Strength :

Lack of metal soundness in a casting is one reason for lower than optimum mechanical properties. The foundryman, by using a sufficient number of foundry techniques such as gating, , chills, padding, and thermal gradients can usually produce soundness even in exceedingly difficultcases of poorly designed castings. However, if certain design principles are observed, the job of producing soundness and uniformly good properties can be made much easier and less costly.

Mass shape and size effects (hot spots) :

Shrinkage cavities of any kind are of course harmful to metal properties. Certain shapes, because of their influence on heat extraction during solidification, are likely cause shrinkage cavities. When ever solidification is delayed at a particular location, that section will show a shrinkage cavity unless adequate feeding from riser occurs.

Hot tears :

Hot tears are another form of metal unsoundness developed during or at the end of freezing of the casting. Some casting alloys have no tendency to hot tear, while others do. Contraction stresses produced by resistance of the mould or other portions of the casting may become large enough to cause rupture (tearing) of the casting. The incidence of tearing is reduced by having a minimum ofa areas where sand is completely or partially surrounded by metal and by uniform distribution of metal thickness.

3.4.4 Design of Gating System

The term gating system includes all the passage ways through which molten metal enters the mould cavity. The gating system is made of the foloving partes

1. Pouring basin.
2. Sprue.
3. Runner.
4. Gates.

The design of a gating system is important and the main requisites of a gating system are :

i) The gating should so designed that it avoids mould or core erosion by reducing metal velocity whithin the cavity and avoiding direct impingement on mould walls or cores.

ii) The flow of metal to the mould cavity should occur with as minimum as possible turbulence, because if turbulence is excessive, the aspiration of mould gases will occur which will oxidise the molten metal. The oxides , so formed, separate more or less completely from the melt and form a dross. To pickup dross or slay, the gating system must eliminate turbulense by (a) use of a well at the sprue base
   (b) avoiding sharp changes in direction,
   (c) filling the mould at the lowest point,
   (d) using the optimum size ingate i.e. filling the mould quickly whilst ensuring that metal flow in laminar.

Pouring basin :

This part is made on or in the top of the mould. molten metal from the ladle is poured in the pouring basin and from here the metal flows to various parts of the mould. Most important aspects of cup or basin design are :

1. They must be large enough t so that the gating system can be chocked rapidly and maintained full.
2. They must be deep enough to permit vortex formation and ;
3. They must be placed in a location such that the ladle can be brought near to it and the metal poured, in a steady , coherent steam.

Sprue :

Tapered sprue are used in moulding. However, for the light metals tapered sprue will eliminate aspiration of air from the sprue side walls into the metal stream. A side wall taper of about 1/4" per feet of sprue height ha been used. From a gating stand point, it is desirable that the sprue be moulded hard and clean rather than be cut with sprue cutter.

Runner :

In large castings, a runner may be used which takes the molten metal from the sprue base and distributes its to several gates around the cavity. Runner may be located either in the cope or in the drag part of the mould. Cross-sectional are of the runner may be about four times the sprue area.

Gates :

Gates are those passage ways which actually lead t into the mould cavity. Bottom gating is used in this investigation. In bottom gating, the metal enters the casting cavity at the bottom. The main advantage ov of gating is that mould erosion and turbulence in the metal flow are minimum.

Runners and gates :

Runners and gates should be designed to obtain the following characterstics :

1. Absence of sharp corners or changes of section that may lead to turbulence or gas entrapment.
2. Proper relation between cross-sectional areas of the several gates, between gates and runners, and between the runners and the sprue.
3. Proper location of the gates to ensure adequate feeding of low-velocity metal into the mould cavity. The gates nearer the sprue will have less metal flowing through them because of higher velocities and lower pressures. This effect is demonstrated by Grube and Eastwood (14), which shows the proportion

of liquid which flows through gates supplying a block casting. In this instance, the total sprue area to total runner area to total gate area was 1 : 2 : 4.

<u>Feeding Castings through the Gating System</u> :

Although the primary function of the gating system is to get the metal into a mould, a secondary purpose may be to get it into the mould in such a way that directional solidification occurs.

<u>Elimination of Slag and Dross</u> :

Use of pouring basins, strainer cores and suitable dams in a gating system helps to filter out slag and dross from the metal stream before it enters the mould cavity. In the case of light metal alloys, the difficulties are some what greater than for copper or ferrous alloys since there is so little difference in specific gravity between the impurities and the metal. Enlargements in the feeding system to reduce the velocity of flow, or special devices such as the whirl gate, which whirls the dross and slag into the centre of the riser, are other means of cleaning the metal. For aluminium casting it has been recommended that the runner be placed in the drag with the ingate in the cope of the mould to reduce the inclusion of dross in the mould cavity by Grube and Eastwood (14). For ferrous metals, on the other hand, the reverse situation has been suggested with the runner in the cope and the ingate in the drag.

Economy and Ease of Removal of Gates and Sprues :

In addition to the factors already discussed it is quite obvious that changes in design of the gating system to reduce costs without affecting the quality of the casting are something for which one should strive. Quite frequently it is found that some modifications in practice such as , for examples the inclusion of a chill in a strategic location may greatlyreduce the amount of metal required to feed a casting. In other instances, it may be found that gating in a particular location will result in much greater ease of removal of the gate than if located in another part of the casting. There are so many factors in connection with each metal and each particular casting that it is still necessary that each particular job be studied individually with the view point of improving the gating system to achieve a quality casting at a minimum cost.

Riser :

The primary function of a riser is to feed metal to the casting as it solidifies. In some instances, it may also be considered as a part of the gating system. The riser requirements depen considerably on the type of metal being poured.

Theoritical Considerations :

If metal in the riser could be kept molten indefinitely, the only metal required would be that necessary to compensate for the contraction in volume occuring during solidification of that part of the casting the riser is intended to feed. Sice this desirable situation can not be realized practically, the next consideration is to f design the riser so that it stays molten longer than the casting. As long as the riser and casting are poured in the some moulding material, the relative solidification rate of riser and casting can be determined by employing Chvorinov's rule. This rule states that the solidification time is proportional to the square of the volume of the metal and inversely proportional to the square of the surface area, or t (solidification time) = $\frac{kV^2}{SA^2}$. Thus, as long as this ratio for the riser is greater than that for the mould, the riser should feed the casting.

Riser Shape :

Since, according to Chvorinov's rule, the lower the surface area per unit volume the lower the solidification rate, a riser should be designed to give the least surface area fper unit volume. Such a shape would be a sphere. It is apparent that spherical shapes in most cases would be difficult to mould or to use as risers; hence cylindrically shaped risers are most re frequently used.

Riser Size :

The diametor of a top riser must be very larger than that of the casting since it would otherwise solidify before the casting, no matter how long it might be made. The height of the riser should be about 1.5 times the diameter with one third of it in the drag and two third in the cope. Additional height is no advantage since it no advantage means also additional surface area, and the extra metal is that merely feeding the lower part of the riser.

Positioning of Risers :

A riser will not function properly unless it is located in a position that will result in directional solidification toward it from the casting. The number of risers that must be assigned to a specific casting will depend upon how many of these directional paths must be operating to secure soundness. Only by risering both heavy sections with a riser greater in diameter than the heavy section and properly padding the casting to promote directional solidification is a sound casting obtained.

Ratio - gating Principles :

Since ratio gating involves sprue, runners, and ingates as one unit it is well to examine their inter-relationships. The sprue, being the minimum area markedly controls the rate of flow. For a fixed sprue size, the orifice coefficient increases rapidly as the ratio changes from 1 : 4 : 1 to 1 : 4 : 4 , a change which shows that the sprue becomes the limiting orifice as the ingates are enlarged. Hence the flow rate is largely determined by the sprue size at gating ratio of 1 : 4 : 4. If gating ratio are used in which the ingate or runner acts as the metering orifice, then obviously those dimensions become the most important in influencing the over-all orifice coefficient. Small changes in their dimensions will then affect the flow rate drastically. In aluminium , it is undesirable to have the ingate function as tge choke, since they will cause a het effect resulting in substaatial drossing and gas entrainment. Since ratio - gating designs for aluminium are aimed at minimum turbulence and smooth metal flow, the time necessary for pouring the casting must be sufficiently prolonged so that excessive metal flow rates are avoided. With pouring basin, sprue, runners, and ingate and flow rate designed to avoid damaged metal, the best results in casting soundness and freedom from defects are obtained.

According to Reddy (15) a risering curve based on the shape factor has been evolved by experiments conducted on A - 6 - M aluminium - silicon alloy. For this, average of casting of varying shape were selected. Different sizes ofrisers were attached to each casting. The castings were then evaluated for soundness by different methods to determine the minimum size of riser to make each casting sound. This is expressed as a riser design curve which can be used in practice to ascertain the size of the required minimum riser.

3.4.5 Effect of Mould Materials

The quality of castings depends on a multitude of interdependent variables. Certain of these factor are quite evidently due to the nature of the metal of which the casting are made. Others are due to the nature of the mould, the mould material, moulding process and method of casting one of the inherent characterstics of the mould which influence casting quality is considered in the following graphs.

Heat Removal :

The surface area of the casting, fundamentally its design , determine the mould cavity area through which the heat must be extracted. However, the mould largely determines the rate at which the heat may be extracted. Its thermal conducting, heat capacity, and characterstics such as size , shape and means of cooling regulate the time required for the molten metal to solidify and the solidified the casting to cool at room temperature. Grain size, segregation, alterrations of the microstructure, changês in response to heat treatment, and other metallurgical properties of casting alloys are affected by differences in cooling rate. However, this point will be considered again in relationship to the metallurgy of the casting alloys. At this point it should be recognised that the thermal conductivity of the mould material does very substantially affect metallurgical casting quality Because of these differences in thermal conductivity of moulding materials, different materials may be used in the same moulds to produce temperature gradients.

3.4.6 Effect of Physical Properties of Moulding sand on Casting Soundness

From a general point of view , the moulding sand must be readily mouldable and produce defect free castings if it is to quality as a good one. Certain specific properties have been identical and testing procedures adopted from their quantitative description.

It is concluded by the author in this work that the casting density , tensile strength and Brinell hardness increases with increase in green permeability to a certain limit, reaches a maximum and with decrease in permeability casting soundness parameters also decreases. Low permeability causes the casting defects such as blow holes and pinholes. For a givenmoisture content , various casting soundness parameters such as casting density, d tensile strength and Brinell hardness, increase with increase in moisture to a certain level, reaches a maximum and subsequently decreases with further increase in moisture content. Excessive moisture content can cause pinholes or blow holes.

Green compression strength and shear strength also effect on casting soundness. Casting soundness parameters increases with increase in green compression strength and green shear strength, attains a maximum and cousiquently decreases with decrease in mould strength. Drop, Dirt, Cuts, and washes such a type of defects are expects due to poor green strength.

Component as a whole , In a sense hardness provides informations similar to the microscopic examination except that the hardness test is more direct and quick and takes into account a number of lathice and grain imperfections.

Casting density takes cause of internal defects such as blowholes, pinholes etc. In many cases intricately cored casting are extremely difficult to measure accurately, particularly the internal sections. It is important for three main reasons to ensure that these sections are correct in thickness:

1) There should be no additional weight which would make the finished product heaviour then permissible,

2) Sections must not be thinner then designed in case of detracting from the strength of the casting;

3) If hollow cavities have been reduced in area by increasing the metal thickness ofthe sections any flow of liquid or gases intended by the designer is reduced.

Murthy (9) has used casting density and ductilig-lity of casting as a soundness parameter in his studies, on S C 70 aluminium alloy.

Ananthanarayanan (10) has used ultrasonic examinations of aluminium alloys LM25 (7%si, 0.3% Mg.) & LM16 (5%si, 1.5%cu, 0.5%Mg) as a soundness parameter.

Lal & Shukla (4) has sudied the aluminium specimen upto a strain rates of 1,100sec as a soundness par deterioration in casting quality.

Gas absorption : Aluminium alloys readily absorb hydro hydrogen, and as the solubility for hydrogen increases, rapidly, with temperature the molten metal should not be taken much above 700°C. Hydrogen is derived from the products of combustion and water vapour in the furnace atmosphere. Gas porosity in aluminium castings is due to hydrogen which is taken into solution in the metal while it is molten and is rejected as the metal cools.

Removal of difficulties :

The above difficulties are removed by fluxing and flushing. Gaseous fluxes used to purge the metal include nitrogen helium, argon and chlorine. The effect of chlorine is very powerful. When it is blown through the alloy, ammonium chloride and hydrogen chloride vapours are formed which carry away bubbles of hydrogen and oxides from the alloy. Elimination by chlorine is carried out by slowly bubling the gas through the bate so that there is a large surface area of contact between the chlorine and the molten metal. Inert gases not react chemically and only carry away the oxides to the surface of the metal.

Flushing is carried out by skimming off surface dross and then bubbling the dry gas through the melt for ten minutes. It is done at a temperature below 700°C to obtain maximum hydrogen removal.

CHAPTER - IV

EXPERIMENTAL INVESTIGATION

The effect of physical properties of moulding sand on soundness of Aluminium castings has been studied, carrying out the experiments keeping all other parameters affecting soundness, constant. Sand shapes and sizes of various elements of gating systems used through out the work and temperature of pouring is also kept constant. Thus an attempt has been made to correlate only the physical properties of moulding sand and soundness through multiple regression analysis.

4.1 Selection of parameters :

To sudy the soundness of castings, tensile strength of castings, Brinell hardness number and casting density have been choosen as soundness parameters as the casting density takes came of internal defects such as blowholes, pinholes etc. and tensile strength, Brinell hardness number take care of soundness with metallurgical point of view such as uniformity in structure etc.

4.1.1 Soundness parameters :

BRINELL HARDNESS TEST :

This test consists in forcing a steel ball of diameter D under a load p into the test piece and measuring the mean diameter d of the identation left in the surfaces after removal of the load. The brinell hardness is obtained by dividing the test load P by curved surface area of the identation. Experiment were carried out by Avery's Brinell Hardness testing machine, Brinell micro-scope specimen. For aluminium and brass, a maximum loading of 750 kgs is suitable.

Tensile Test :

The machine used for tensile test consists essentially of a device for applying a steadily increasing load to a test piece of metal. The device for applying the load are usually of a hydraulic type. The load is indicated on a calibrated dial. The material specimen is firmly held in the grips of the testing machine without slippage when the load is applied.

Casting density test :

This test is carried out by accurately weighing each and by measuring the displacement caused by immersing the casting in a suitably filled measuring jar or vessel. The casting is obtained by dividing the casting weight by displacement volume.

4.1.2 Moulding Sands Constituents

Moulding sands are actually mixtures of three or more constituents. A green sand always contains clay and water as well as the principal sand constituent, SiO_2.

Sand Used :

Ganga river sand available near Haridwar, Uttar pradesh is used to prepare sand mixes.

Clay used :

Natural moulding sand which contains about 20% clay and remaining Silica sand of fine sizes were used.

Sand mix required for making the green sand mould is prepared by throughly mixing silicon sand with clay and water in a suitable mixer. 5 kg batch capacity laboratory muller was used for preparing the sand mix. In all the experiments clay was added to the dry sand and mixed for 3 minutes, followed by the addition of water and mixed further for 3 minutes.

In each sand / clay sample the water content was varied from 3 to 14 percent.

The various physical properties of the sand mix such as green permeability, green hardness, bulk density, green compression strength, and green shear strength were determined using Rids dale Dietert permeability meter, green harness tester and hydraulic universal sand strength testing machine.

4.1.3 **Moulding sand conditions**

Since moulding sand is composed of several materials, it is necessary to mix these components properly in order to obtain uniform and satisfactory results. At the same time , the various properties must be controlled so as to as certain the desired results. Moulds are prepared out of moulding sand (80% natural moulding sand plus 20% Silica sand) with different water contents (3 to 14%). To attain the similarity in the mould condition and AFS tet Test specimen wonditions, hardness of moulding is choosen as a parameter.

Average mould hardness No. 50 is kept constant throughout the investigations. Test specimens were also rammed in the same hardness to maintain similarity in the moulding sand properties in the mould in the test specimen.

4.1.4 Pouring Temperature

Immersion thermocouples consisting ofgauge asbestos covered Chromel -alumel wire are suitable for this measurement. The bare couple is satisfactory for rapid temperature measurement. A pouring temperature
proper amount of water and ramming of the sand thus favour thermal stability according to this theory (2).

Clay content and other properties :

So many properties are influenced by the clay type and amount in moulding sands that it is not possible to consider them all here. some sands have been found resistant to flow during moulding. Soft spots and porous areas in the mould result in casting swells and roughness(6). Mould hardness tests of the mould cavity are useful in studying the uniformity of sand flow during moulding.

Sand - mixing problems are also related to the clay ingredient. Good mixing is supposed to cause unifirm coating of the sand grains with clay.

Effect of Moisture content :

It is evident from the preceding discussion that close control of the moisture content of moulding sands is exceedingly important because of the many properties affected by it.

A series of experiemtns conducting by the author(7) that the green compression strength, green shear strength decreases with increase in moisture content. Green permeability and bulk density increases with increase in moisuture content and attains a maximum but consiquently decreases green permeability with further increase in moisture content.

Effect of Mulling time :

Experiments have carried out by author (7) that for the the same percentage of sandsm , clay and water, the physical properties of the sand mixture will vary with the mulling time as well as with the method of addition and the type of muller, of 1250 to 1400 F may be employed depending on casting size, alloy composition and a number of other factors. Selection of the proper temperature is essential to producing the most desirable castings.

Castings are made in aluminium alloy because of low temperature of melting and ease of availability.

All the castings are poured at the same temperature ($700^{o}C$) to avoid the variations in H_2 gas absorption due to variation of pouring temperature and thus to avoid the possible variation of gas porosity due to this factor.

4.1.5 Design of pattern for Test Specimens

Pattern are the foundryman's forming tool. The mould cavity, and therefore the casting, is made from the pattern. Even if only one casting is desired, it is necessary to have a pattern, but a great many castings may be made from a single pattern. Obtaining a suitable pattern is thus the first in making castings.

Types of patterns :

Several type of pattern are used in foundaries. Depending on the casting requirements, the pattern may conform to one of the following types :

1. Single patterns Loose patterns.
2. Gated patterns (Loose)
3. Match plate patterns.
4. Cope and drag patterns.

Loose patterns :

Loose patterns are single copies of the casting but incorporating the allowances and core prints necessary to producing the casting. They generally one of wood construction but may be made of metal, plaster, plastics, wax or any other suitable material. Relatively few castings are made from any one loose pattern since hand moulding is practical and the process is slow and costly. The parting surface may be hand-formed. Gating systems one hand -cut in the sand. Drawing the pattern from the sand is also done by hand after it is rapped to loosen it from the sand. Consiquently casting dimensions vary.

Gated Patterns :

Gated patterns are an improvement on ungated loose patterns. The gating system is actually a part of the pattern and eliminates hand cutting of the gates. More rapid moulding of small quantities of castings results with this type of pattern especially when used in conjuction with a follow board or match.

Match - Plate Patterns :

Large quantity production of small castings requires match plate patterns or more specialised types of pattern equipment. The cop and drag portions ofthe pattern are mounted on opposite sides of a wood or metal plate conforming to the parting line. Match plates are also integrally cast , in which case pattern and plate are cast as one piece in sand. Gating systems are almost are always attached to the plate. . The improved production rate possible with these patterns serves to compensate for their increased cost. Plates also increase the dimensional accuracy of the castings A limitation of the match -plate pattern arises in the weight which can be handled by the moulder.

Cope and Drag Pattern Plates :

Cope and drag pattern plates consist of the cope and drag parts of the pattern mounted on seperate plates. The cope and drag halves of the mould may thus be made seperately by workers, on different moulding machines. The moulding ofmedium and large castings on moulding machines is greately facilitated by this type of pattern equipment. Seperate cope and drag plates are amore costly type of pattern equipment, but this is usually justified by increased product ion or the making of large moulds which could not be handed with match - plate equipment. Seperate pattern plates require accurate d alignment of the two mould halves by means of guide and locating pins and bushings in order that the upper and lower parts of the casting will match.

Pattern Allowances :

Although the pattern is used to produce a casting of the desired dimensions, it isnot dimensionally identical with the casting, For metallurgical and mechanical reasons, a number of allowances must be made on the pattern ifthe casting is to be dimensionally correct.

Shrinkage Allowance :

Shrinkage allowance on pattern is a correction for solidification shrinkage of the metal and its contraction during cooling to room temperature. The total contraction is volumetric , but the correction for it is usually expressed linearly. Pattern shrinkage allowance is the amount the

the pattern must be made larger , from the casting to provide for total contraction.

Machine finish allowance :

Machine finish allowance is the amount dimensions on a casting are made oversize to provide stock for machining. In general, machine finish allowance may be a minimum ifthe surfaces to be machined are entirely in the drag half of the mould, since dimensional variation and other defects are usually least prevalent there.

In the present work gated patterns are used. In gated pattern the gating -system is actually a part of the pattern, and eliminates hand cutting of the gate more rapid moulding of small quantities of castings results with this type of pattern, to allow rapid moulding of Aluminium casting to avoid the possible variation of drossing and gas absorption which are incorporated during Aluminium casting.

4.1.6 Casting Materials

Aluminium is used as casting material because of the numerous desirable properties include the following :

1. A Wide range of mechanical properties :

Strength , hardness , and other properties may be greately altered by alloying and /or heat-treatment.

Properties of the strongest alloys can be favourably compared with those of the cast irons and lower strength steels, especially if the weight factor is considered. Suitable strength for many engineering uses is is thus available.

2. Casting Properties :

Since aluminium has a relatively low melting point, about 1200°F, the problems of melting and pouring are greately simplified when compared with steels and cast irons. Problems with furnace refractories and moulding sands are reduced of the lower pouring temperatures.

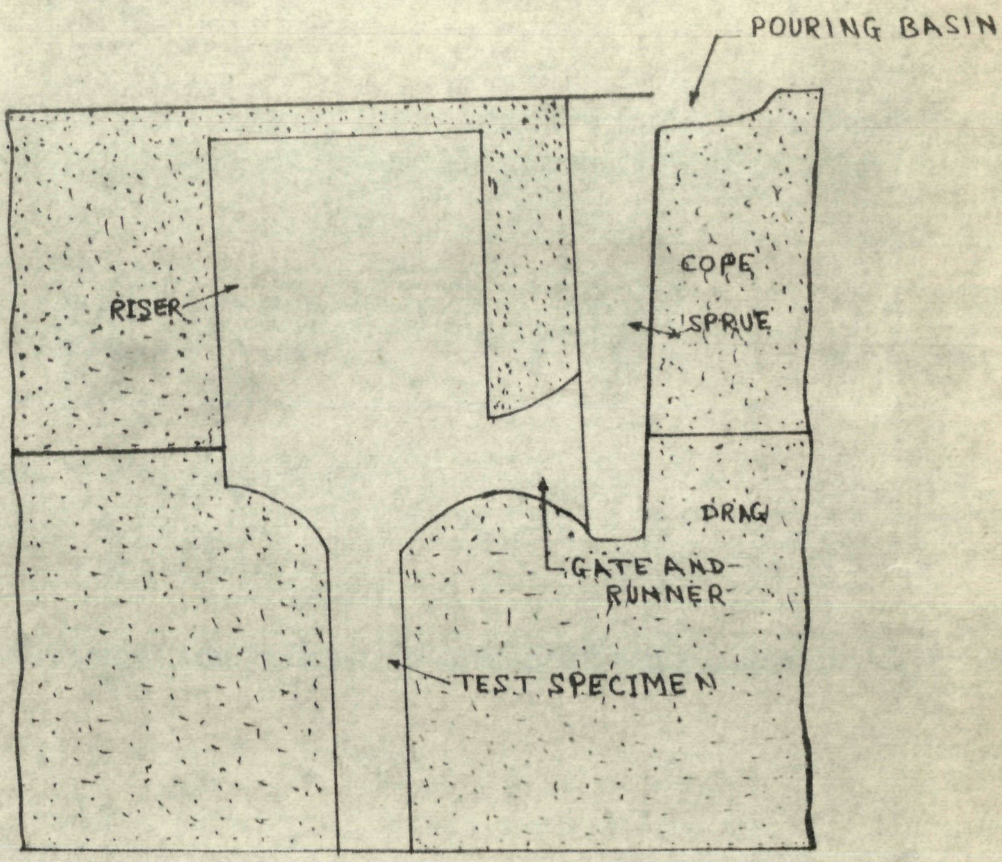


Fig. 1(a) – Elements of Gating Systems for Sand Castings

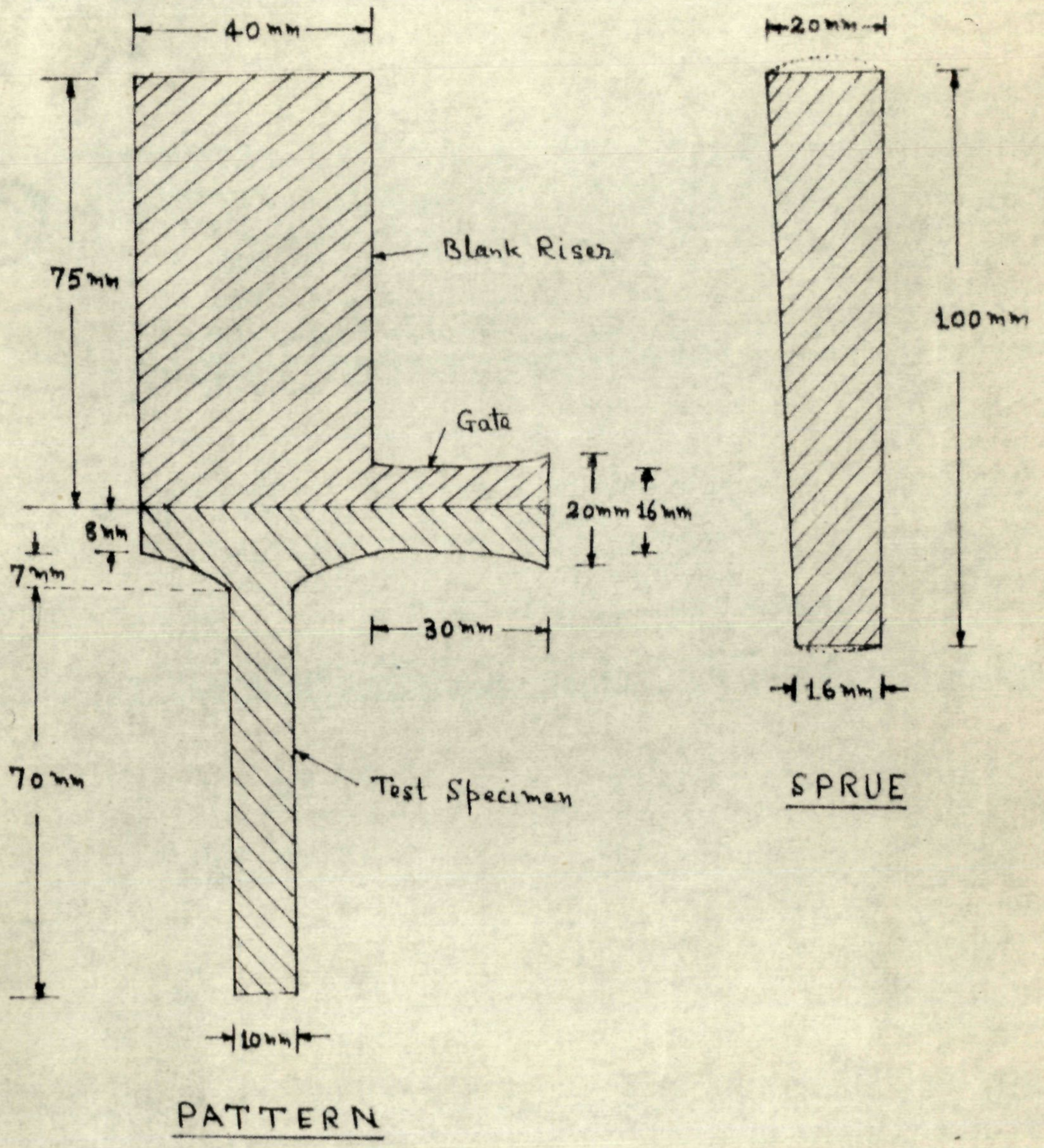


Fig. 1(b) – Actual Dimensions of Pattern and Sprue

MELTING OF ALUMINIUM AND ITS ALLOYS

Furnaces :

Melting furnaces fo aluminium may be heated by solid fuel , oils , gas or electricity and may be any of the following ; Crucible furnaces, reverberatory furnaces, and induction furnaces, In molten foundaries, melting down and alloying addition is often carried out in oil fired reverberatory or crucible units, or in low - frequency induction furnaces, and the metal is transferred to heated pots which act as holding furnaces. Indirect heating is preffered to direct firing because the metal picks up gas easily.

Melting Procedure :

The charge usually consists of 30 to 70% scrap and rest pre-alloyed aluminium pig. The charge is melted and held at a temperature 700^{0}C while the low melting metals (Zinc, tin and Magnesium)are added and stirred in with an iron rod. When magnesium is added, it is liable to burn and to prevent it from burning on the slag, it must be pushed below the surface with an inverted perforated cup on the end of a strirrer fod. The melt must be stirred from the bottom upward and core should be taken to disturb the surface as little as possible. Higher melting point metals (Copper, nickel, Silicon, magnese etc.) are usually not added in the molten aluminium in the elemental form. They are best added as rich alloys or hardeners. Hardners usually have a melting point close to that of the basic element. Thus for instance, the melting point of aluminium is 658°C, while that of aluminium - silicon hardener is about 640°C. Pyrometric control is essential in aluminium melting. Suitable casting temperature for a particular design of casting should be cast, as far as possible, at the lowest temperature at which the section can be run, allowing air bubbles and dross to escape, because rapid solidification gives strong and sound aluminium castings.

Difficulties in melting :

The main difficulties experienced in the aluminium m melting practice are :

1. Drossing
2. Gas absorption.

Drossing :

Drossing is the formation of aluminium oxide and other oxides which get collected on the melt surface. Aluminium alloys easily react with water vapour, and other combustion products. Thus, dross formation can be minimised if the charge is protected from combustion products and the melting process is rapid. Seperation of dross from the molten metal depends on the difference in their specific gravities. In case of aluminium, however, the sp. gr. differen-ce is very small and separation of dross is not easy. The oxides film mixes with the alloy and forms aluminium oxide inclusions, thus causing a serious deterio-

4.2 Experimental Studies :

Experiments were carried out to study the effect of various physical properties of the moulding sand on various mechanical properties and casting soundness.

1. Study of theeffect of moisture content on Casting soundness parameters :

Tensile Strength :

From Fig. (15) one can conclude that,

i) for a given moisture content, tensile strength increases with increase in moisture content to a certain extebt, reaches a maximum and sbusequently decreases on further increase in the moisture content.

ii) The tensile strength attains a maximum value around a moisture content of 6% for all the moisture content studied,

Brinell hardness No. :

From Fig. - (15) one can infer that ,

i) for a given moisture content, Brinell hardness No. increases with increase in the moisture content, reaches a maximum and subsequently decreases on further increase in the moisture content.

ii) The Brinell Hardness No. attains a maximum value around a moisture content studied.

Casting Density :

For a given moisture content, with increase in moisture content, casting density gradually increases as shown in Fig. 15, reaches a maximum and subsequently decreases. The Fig. also indicates that the casting density is maximum at a moisture content of 6% for all the moisture content employed.

2. Study of the effect of green permeability on Casting soundness parameters :

Tensile strength :

A study of Fig. 16 indicates that the tensile strength increases with increase in green permeability. The curve also shows some fluctuations in the tensile strength , between a permeability range of 8 to 9.5, the tensile strength seem to increase constantly.

Brinell hardness No. :

From the Fig. 16 one can conclude that the Brinell hardness No. increases linearly with increase in green permeability. Some fluctuations is observed in the Brinell hardness between a permeability range of 7.5 to 9.5.

Casting density :

From Fig. 16 it could be infer that with the increase in permeability, casting density increases gradually and attains a maximum value at a green permeability No. of 8.8 and subsequently decreases with further increase in green permeability no.

3. **Study of the effect of mould hardness number on casting soundness parameter :**

Tensile strength :

From Fig. 17 itm may be concluded that the tensile strength increases simultaneously with increase in green hardness No., attain a maximum at 51 mould hardness No. It also observe that tensile strength decreases with further increase in mould hardness No.

Brinell hardness No. :

From Fig. It m is observed that Brinell hardness no. increases at certain extent and reaches a maximum at 46 mould hardness no, and decreases with further increase in mould hardness No.

Casting Density :

A study of Fig. 17 indicates that the casting density increases with increase in mould hardness No., reaches a maximum around a mould hardness no, of 51 and decreases with further increase in mould hardness No.

4. Study of the effect of green compression strength on casting soundness parameters :

Tensile Strength :

From Fig. 18 one can infer that the tensile strength increases contineously to a certain extent, attains a maximum value around a compression strength of 10.8 (g./cm^2) x 100 for all the compression strength studied and subsequently decreases with further increase in compression strength.

Brinell hardness No.

From Fig. 18 one can infer that the Brinell hardness No. increases gradually with increase in compression strength, reaches a maximum at compression strength of 11.0 (gm/cm^2) x 100 and subsequently decreases with further in compression strength.

Casting density :

A study of Fig. 18 indicates that the casting density increases with increase in green compression strength, attains a maximum value around a compression strength of 10.8 (gm/Cm^2) x 100 and subsequently decreases with further increase in green compression strength.

5. Study of effect of interrelationships of Casting Soundness parameters :

Tensile Strength :

From Fig. 19 it can observe that the tensile strength increases with increase in casting density and decreases continuously with further increase in casting density.

Brinell hardness No. :

A study of Fig. 19 indicates that Brinell hardness No. gradually increases in casting density and further increase in casting density. Some fluctuations in the Brinell hardness No. arrives in between 2.6 to 2.65 gm/c.c. of casting density and further increase in casting density the Brinell hardness No. increases continuously.

Table 6.6

Table beteeen Physical properties of natural moulding Sand and Mechanical Properties of Aluminium Castings :

%cent Moisture	Green Permeability No.	Green Hard- No.	Green Compress- Strength (gm/Cm^2)x100	Casting Density (gm/c.c.)	Tesile Strength Tons	Brinell Hard- No.
3	9.5	45	9.3	2.65	1.40	67.81
4	10.2	48	11.0	2.62	1.84	74.11
6	8.8	51	10.8	2.70	1.86	71.36
8	8.2	46	11.5	2.60	1.43	62.86
10	7.6	46	10.3	2.69	1.73	69.25
12	4.9	50	8.9	2.60	1.27	68.24
14	0.9	55	10.8	2.29	1.16	63.29

Percent Clay Content = 15 % ⊙——⊙ Casting Density

Mulling Time = 6 mts. ⊡——⊡ Tensile Strength

Ramming = 2 times △——△ Brinell Hardness No.

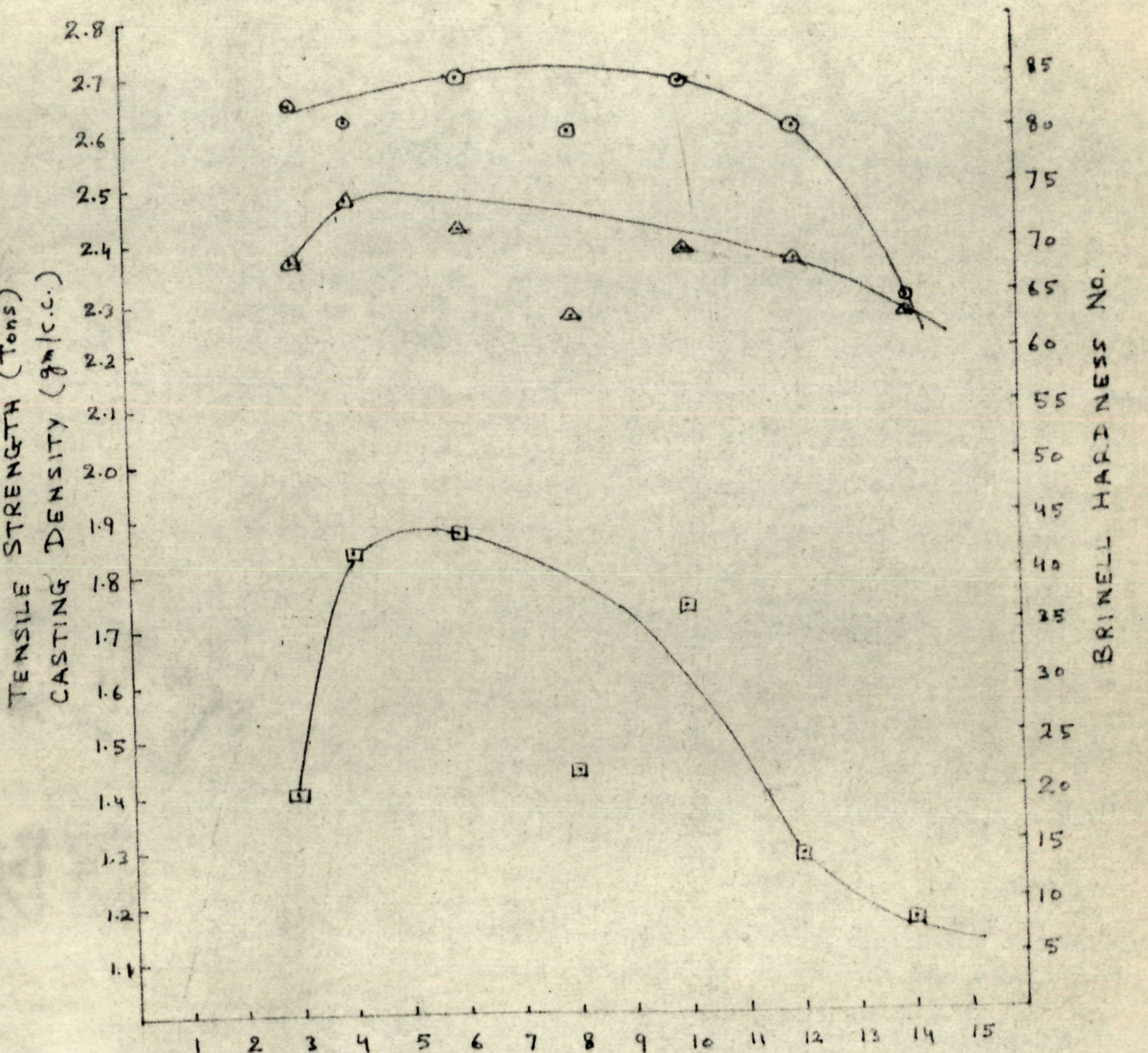


Fig.(15): Effect of Moisture Content on Casting Soundness Parameters

Percent Clay Content = 15 %
Mulling Time = 6 mts.
Ramming = 2 times

o—o Casting Density
□—□ Tensile Strength
△—△ Brinell Hardness No

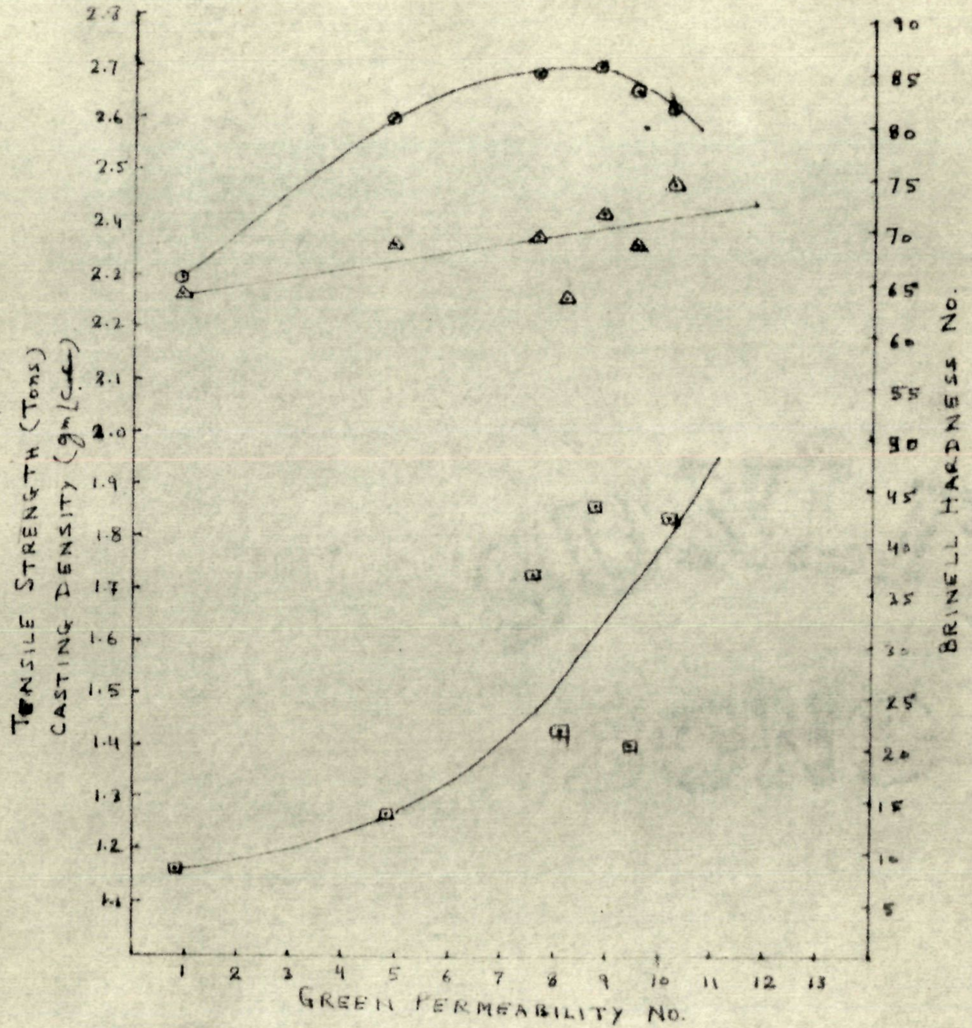


Fig.(16): Effect of Green Permeability No. on Casting Soundness Parameters

Percent Clay Content = 15%
Mulling Time = 6 mts.
Ramming = 2 times

Scale:
X-axis : Green hardness 1cm = 5 G.H.
Y-axis : Casting Density 1cm = 0.1 gm/c.c.)
Tensile Strength 1cm = 0.1 (Tons)
Brinell Hardness 1cm = 5 B.H.

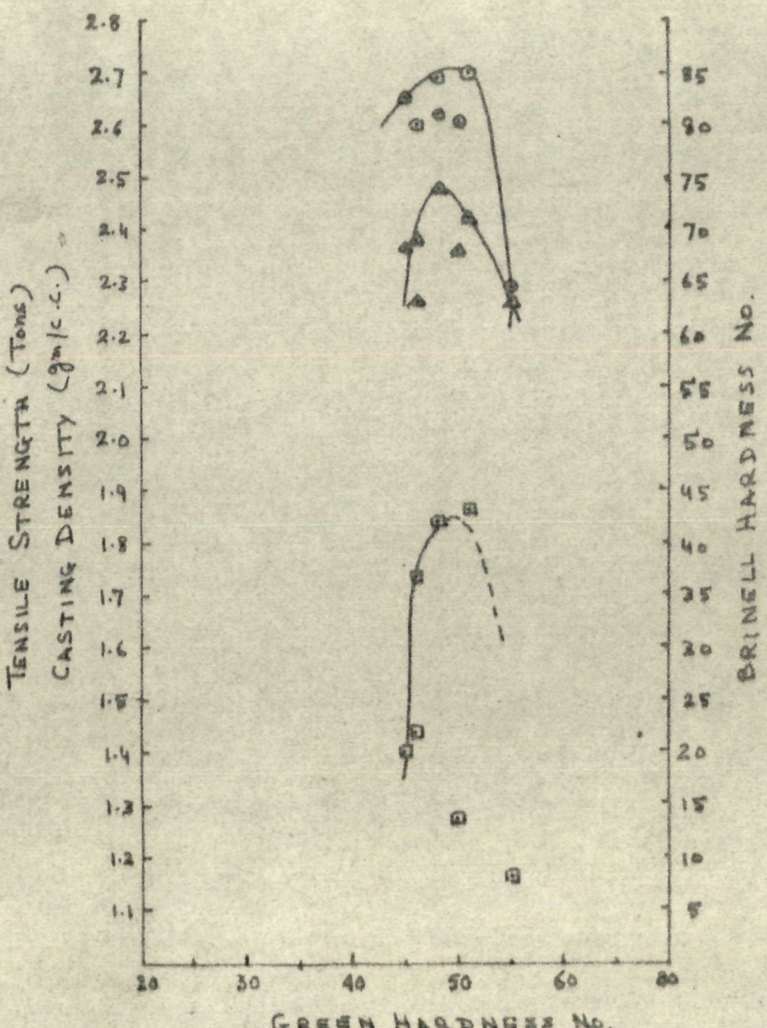
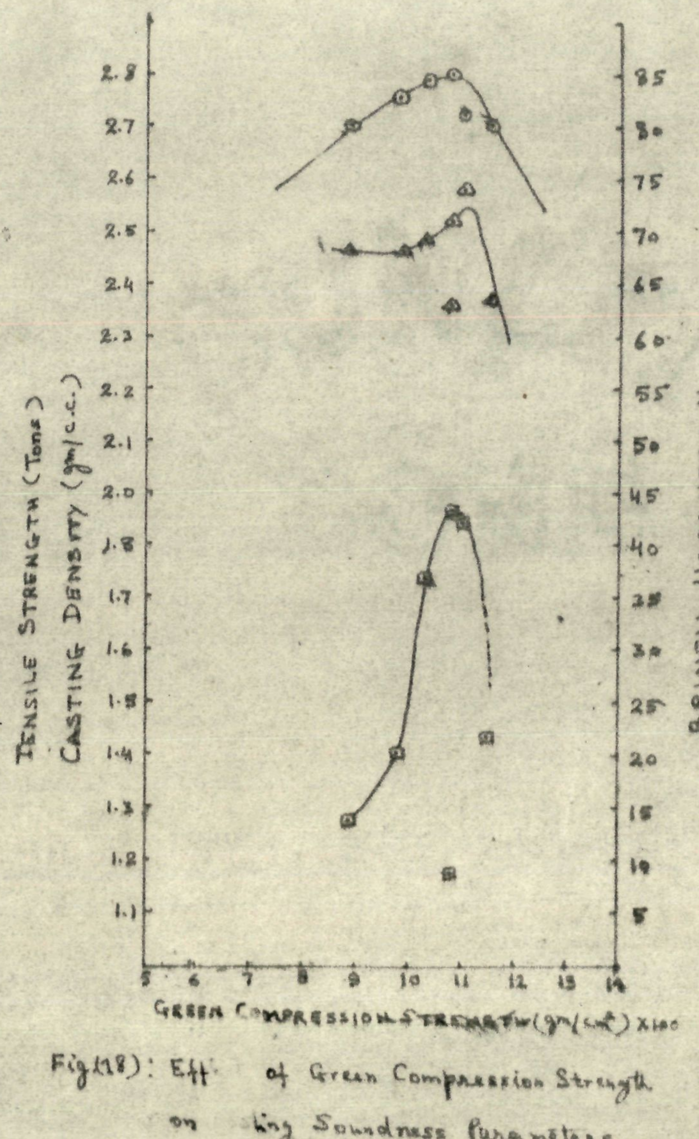


Fig.(17): Effect of Green Hardness No. on Casting Soundness Parameters

Percent Clay Content = 15%
Mulling Time = 6 mts.
Ramming = 2 times

○———○ Casting Density
□———□ Tensile Strength
▲———▲ Brinell Hardness



Fig(18): Eff of Green Compression Strength on ing Soundness Parameters

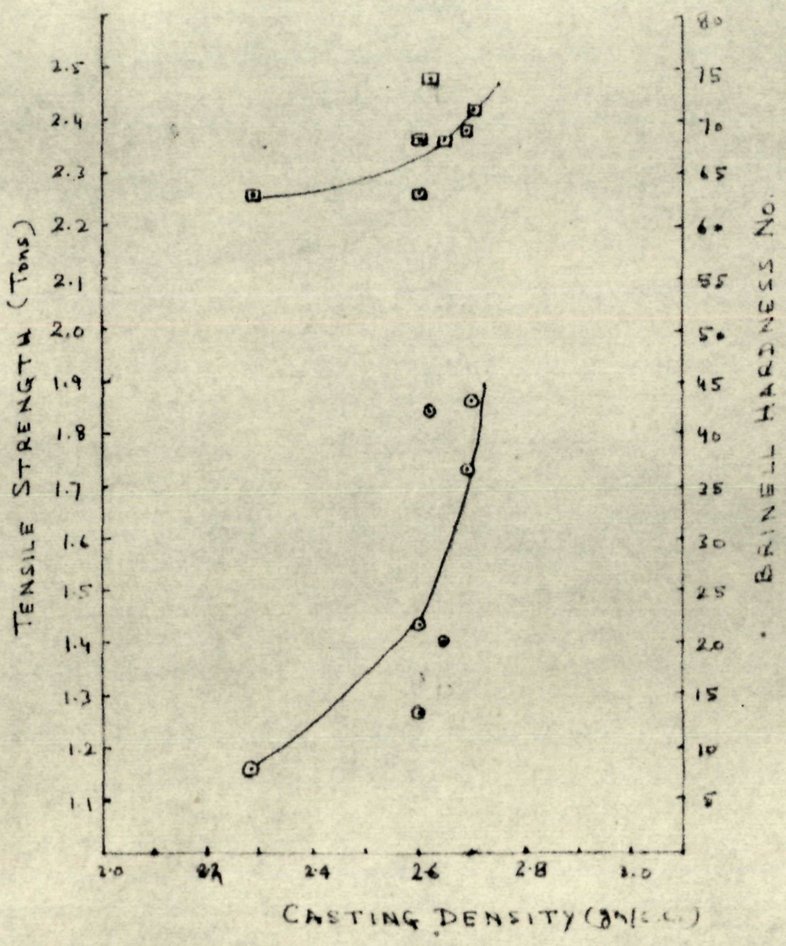
X-axis:

Casting density 1cm = 0.1/gm/c.c.

Y-axis:

⊙—⊙ Tensile Strength 1cm = 0.1 (Tons)

⊡—⊡ Brinell hardness No. 1cm = 5 B.H.



* Fig.(19): Effect of Inter-relationships of Casting Soundness Parameters

4.3 Development of Cause and Effect type relationships Through Multiple Regression Analysis :

Assuming that the relationship between the cause and which can be treated as independent variables and their effects have a definete relationship, This relationship can be described mathematically as :

$$Y = f (X_1 , X_2 , X_3 , \ldots\ldots)$$

In the present study the effects are taken to be the attributes of castings. These attributtes are :

1) Brinell Hardness No.
2) Tensile strength.
3) Casting density.

The independent variables which could be treated as causes for the above mentioned effects are as follows:

1) Green permeability No.
2) Percent moisture content.
3) Green mould hardness No.
4) Green compression strength.
5) Green shear strength.
6) Bulk density of moulds.

Developing relationships between dependent variables individually with independent variables as listed above through multiple regression technique a definete mathematical relationship is possible to be achieved.

Relations between several variables :

In many cases several factors are relevent to the prediction of just one variable. The relation between height and weight of an individual is different at different edges and different for men and women, and estimate of weight based on height , age and sex will be better than one based on height alone. The relation between tensile strength and Rock - well hardness may depend on the density on the specimens. For each hardness density combination the tensile strength will vary about a certain mean. We are interested in a formula given the mean for each combination. As in the case of the single variable, it is assume that the variance will be the same for each combination.

Least Squares equations :

Suppose for example, we are interested in predicting Y and Let X_1 and X_2 be the independent variables. Assume that true under lying relationship is of the forms.

$$\text{Average value of } Y = B_0 + B_1X_1 + B_2X_2$$

If we denote the estimate of the B_1 by b_1 . Then least squares estimates is $\bar{Y} = b_0 + b_1 X_1 + b_2 X_2$

Where b_1 and b_2 are found from the following set of the equation.

$$\sum_{i=1}^{n} (y_i - \bar{y})(x_{1i} - \bar{x}_1) + = b_1 \quad (x_{1i} - \bar{x}_1)^2 + b_2 \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)$$
$$(x_{2i} - \bar{x}_2)$$

$$\sum_{i=1}^{n} (y_i - \bar{y})\ (x_{2i} - \bar{x}_2) = b_1 \sum_{i=1}^{n} (x_{2i} - \bar{x}_1)\ (y_{2i} - \bar{x}_2) + b_2 \sum_{i=1}^{n} (x_{2i} -$$
$$\bar{y}_2\ )^2$$

$$b_0 = \bar{y} - b_1\ \bar{x}_1 - b_2\ \bar{x}_2$$

These equation are known as normal equation and can be relevent by solving the first for b_1 in terms of b_2 and subutituting this expression for b_1 in the second or by any other method. In general we might consider a regression equation of the sort even ago value of $y = B_0 + B_1X_2 + \cdots\cdots \cdots\cdot B_kX_k$

with estimate

$$\bar{y} = b_0 + b_1x_1 + b^{b_2}x_2 + \cdots\cdots \cdots\cdots + b_kx_k$$

where $b_1, b_2 \cdots\cdots b_k$ are found by the solution of a set of K simultaneously equation in K unknown. for K = 2 and 3 detailed extraction are given in the table A and Table B.

Test of significance :

There are many hypotheses which might be interesting in testing, but the most important equation is whether the independent variables taken as awhole lead to an improvement in our ability to for cast Y

For $K = 2$ this is equivalent to testing the hypotheses that $(B_1, B_2) = (0, 0)$ i.e. value of $y = B_0$. The results may be arranged into table below

REGRESSION TABLE FOR K = 2

Variation	Sum or square	Degree of freedom	Mean square
Due to regression	$b_1c_1 + b_2c_2$	2	$(b_1c_1+b_2c_2)/2$
About regression	$\sum_{i=1}^{n} (Y_i - \bar{Y}_i)^2$	$n - 3$	$\sum_{i=1}^{n} (y_i - \bar{y}_i)/n-3$
Total	$\sum_{i=1}^{n} (y_i - \bar{y})^2$	$n - 1$	

Where c_1 and c_2 are defined in the computational table and $\sum_{i=1}^{n} (y_i - \bar{y}_i)^2$ is obtained by substraction

Reject the hypohtesis that $(B_1, B_2) = (0, 0)$ if

$$F = \frac{(b_1c_1 + b_2c_2)/2}{\sum_{i=1}^{n} (Y_i - \bar{Y}_i)^2 / n-3} \geqslant F_{\alpha}, 2, n-3$$

Where $F_{\alpha}, 2, n - 3$ is the percentage point of the F distribution

For $K = 3$ to test $H_0 : (B_1, B_2, B_3) = (0, 0, 0)$ arrange the results into table given below :

Variation	sum of square	degree of freedom	mean square
Due regression	$b_1c_1 + b_2c_2 + b_3c_3$	3	$(b_1c_1+b_2c_2+b_3c3)/3$
About regression	$\sum_{i=1}^{n} (Y_i - \bar{Y}_i)^2$	$n - 4$	$\sum_{i=1}^{n} (Y_i - \bar{Y}_i)/ n - 4$

Where C_1, C_2 and C_3 are defined in the computational table B and $\sum_{i=1}^{n} (y_i - \bar{y}_1)^2$ is obtained by is obtained by subtraction.

Reject the hypothesis that $(B_1, B_2, B_3) = (0, 0, 0)$ if

$$F + = \frac{(b_1c_1 + b_2c_2 + b_3c_3) / 3}{\sum_{i=1}^{n} (y_i - \bar{y}_2)^2 / (n - 4)}$$

Where F , 3n - 4 is the percentage point of the F distribution

Table A

Computational scheme for solving the normal equations :

$$\bar{Y} = b_0 + b_1x_1 + b_2x_2$$

The normal equations as are given below

$$a_1b_1 + a_2c_2 + C_1$$

$$a_{21} b_1 + a_{22}b_2 + C_2$$

Where

A $a_{11} = \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)^2 = \sum_{i=1}^{n} x_{1i}^2 - n \bar{x}_1^2 =$ ____________

$a_{21} = a_{12} = \sum_{i=1}^{n}(x_{1i} - \bar{x}_1) (x_{2i} - \bar{x}_2) = \sum_{i=1}^{n}(x_{1i}x_{2i} - n\bar{x}_1\bar{x}_2) = -$

$a_{22} = \sum_{i=1}^{n} (x_{2i} - \bar{x}_2)^2 = \sum_{i=1}^{n} x_{2i}^2 - n \bar{x}_2^2 =$ ____________

$$C_1 = \sum_{i=1}^{n} (x_{1i} - \bar{x}_1) (y_i - \bar{y}) = \sum_{i=1}^{n} x_{1i}y_i - n\bar{x}_1\bar{y} = \text{—}$$

$$C_2 = \sum_{i=1}^{n} (x_{2i} - \bar{x}_2)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{2i}y_i - n\bar{x}_2 \bar{y} = \text{—}$$

Operation.

	b_1	b_2	c	Check
1.	a_{11}	a_{12}	c_1	$a_{11} - a_{12} - c_1$
2.	a_{21}	a_{22}	c_2	$a_{21} + a_{22} + C_2$
3. (1) repeated	μ_{11}	μ_{12}	μ_{13}	
4. ( ) divided	1	v_{12}	v_{13}	
5. (2) - v_{12} x (3)	0	μ_{22}	μ_{23}	
6. (5) divided	0	1	v_{22}	

Solution

(7) $b_2 = v_{23}$

(8) $b_1 = v_{13} - v_{12}b_2$

(9) $b_0 = \bar{Y} - b_1\bar{x}_1 - b_2\bar{x}_2$

The check is started with line 3 all the operation from line 3 on are performed on the values in the check colum. For each line then the sum of the entries in all the columes should check with the entry in the check column.

COMPUTATIONAL SCHEME FOR SOLVING THE EQUATIONS :

Table - B

$$\bar{Y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3$$

The normal equation are of the form

$$a_{11} b_1 + a_{12} b_2 + a_{13} b_3 = C_1$$

$$a_{21} b_1 + a_{22} b_2 + a_{23} b_3 = C_2$$

$$a_{31} b_1 + a_{32} b_2 + a_{33} b_3 = C_3$$

Where,

$$a_{11} = \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)^2 = \sum_{i=1}^{n} x_{1i}^2 - n\bar{x}_1^2 = \_\_\_\_$$

$$a_{21} = a_{12} = (x_{1i} - \bar{x}_1)(x_{2i} - \bar{x}_2) \sum_{i=1}^{n} x_{1i} x_{2i} - n\bar{x}_1 \bar{x}_2 = \_\_$$

$$a_{22} = \sum_{i=1}^{n} (x_{2i} - \bar{x}_2)^2 = \sum_{i=1}^{n} x_{2i}^2 - n\bar{x}_2^2 = \_\_\_\_$$

$$a_{13} = a_{31} = \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)(x_{3i} - \bar{x}_3) = \sum_{i=1}^{n} x_{1i} x_{3i} - n\bar{x}_1 \bar{x}_3 = \_\_$$

$$a_{23} = \sum_{i=1}^{n} (x_{2i} - \bar{x}_2)(x_{3i} - \bar{x}_3) = \sum_{i=1}^{n} x_{2i} x_{3i} - n\bar{x}_1 \bar{x}_3 = \_\_\_$$

$$a_{33} = \sum_{i=1}^{n} (x_{3i} - \bar{x}_3)^2 = \sum_{i=1}^{n} x_{3i}^2 - n\bar{x}_3^2 = \_\_\_\_$$

$$c_1 = \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{1i} y_i - n\bar{x}_1 \bar{y} = \_\_$$

$$c_2 = \sum_{i=1}^{n} (x_{2i} - \bar{x}_2) (y_i - \bar{y}) = \sum_{i=1}^{n} x_{2i} y_i - n\bar{x}_2\bar{y} = \_\_\_\_\_\_$$

$$c_3 = \sum_{i=1}^{n} (x_{3i} - \bar{x}_3) (y_i - \bar{y}) = \sum_{i=1}^{n} x_{3i} y_i - n\,\bar{x}_3\bar{y} = \_\_\_\_\_\_$$

Operation	$i = 1$				*Check
(1)	b_1	b_2	b_3	c	
(2)	a_{11}	a_{12}	a_{13}	c_1	
(3)	a_{21}	a_{22}	a_{23}	c_2	
(4) (1) repeated	a_{31}	a_{32}	a_{33}	c_3	
(5) (4) divided	μ_{11}	μ_{12}	μ_{13}	μ_{14}	
(6) (2) - V_{12} x (4)	1	V_{12}	V_{13}	V_{14}	
(7) (6) divided by μ_{22}	0	μ_{22}	μ_{23}	μ_{24}	
(8) (3) - V_{13} x (4) - V_{23} x (6)	0	1	V_{23}	V_{24}	
(9) (8) divided by μ_{33}	0	0	μ_{33}	μ_{34}	
	0	0	1	V_{34}	

*Check

$a_{11} + a_{12} + a_{13} + c_1$

$a_{21} + a_{22} + a_{23} + c_2$

$a_{31} + a_{32} + a_{33} + c_3$

Solution

(10) $$b_3 = V_{34}$$

(11) $$b_2 = V_{24} - V_{23}b_3$$

(12) $$b_1 = V_{14} - b_3V_{13} - b_2V_{12}$$

(13) $$b_0 = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2 - b_3\bar{x}_3$$

The check is started with line 4. All the operations from line 4 on are performed on the values in the check column. For each line, then, the sum of the entries in all the columns should check with the entry in the check column.

Multiple - Regression Analysis

Dependent Variables

X_1 - Brinell Hardness No.

X_2 - Casting Density.

X_3 - Tensile Strength.

Independent Variables

X_4 - Green Permeability No.

X_5 - Percent Moisture Content.

X_6 - Mould Hardness No.

X_7 - Green Compression Strength.

X_8 - Green Shear Strength.

X_9 - Bulk density of Mould.

Assuming the relationship to be of following nature :

$$Y_1 = A\, X_1^{B}\, X_2^{C}\, X_3^{D}$$

Taking log on both sides :

$$\log Y_1 = \log A + B \log X_1 + C \log X_2 + D \log X_3 + \cdots + J \log X_9$$

This become a linear equation and knowing to the value of the coefficients A, B, C, D etc. one can develope a relationship between dependent and independent variables.

If Y_i ($i = 1, 2, 3$) being dependent variables as listed earlier and X_i ($i = 1$, to 6) being independent variables. A multiple regression package program as given in appendix (A) was used for the following combinatorial sets in order to identify the best a fit equation.

The program was run for the following selection to identify the best fit equation.

X_1 Vs X_4, X_5

X_4, X_6

X_4, X_7

X_4, X_8

X_4, X_9

X_5, X_6

X_5, X_7

X_5, X_8

X_5, X_9

X_6, X_7

X_2 Vs X_4, X_5

X_4, X_6

X_4, X_7

X_5, X_6

X_5, X_7

X_5, X_8

X_5, X_9

X_3 Vs X_4, X_5

X_4, X_6

X_4, X_8

X_5, X_6

X_5, X_7

X_5, X_8

X_5, X_9

X_1 Vs X_4, X_5, X_6

X_4, X_5, X_7

X_4, X_5, X_9

X_4, X_6, X_7

X_5, X_6, X_7

X_2 Vs X_4, X_5, X_6

X_4, X_5, X_7

X_4, X_6, X_7

X_5, X_6, X_7

X_3 Vs X_4 , X_5 , X_6

X_4 , X_5 , X_7

X_4 , X_6 , X_7

X_5 , X_6 , X_7

The results of multiple regressions analysis are tabulated in table - 6.7 to 7.3 the combination having multi-co-relation coefficient above 0.9 have been selected.

Independent Variables	Set I Regression Coeff.	Set II Regression Coeff.	Set III Regression Coeff.	Set IV Regression Coeff.	Set V Regression Coeff.	Set VI Regression Coeff.	Set VII Regression Coeff	SetVIII Regression Coeff.	Set IX Regression Coeff.	Set X Regression Coeff.
X_4 Green permeability No.	2.20235	1.27439	1.16851	1.05429	1.05429	-	-	-	-	-
X_5 Percent Moist. Content	-1.20228	-	-	-	-	1.57136	1.30651	1.05448	1.05448	-
X_6 Mould Hardness No.	-	-0.26137	-	-	-	-0.54488	-	-	-	2.01622
X_7 Green comp. Strength	-	-	-0.15301	-	-	-	-0.27862	-	-	-1.12040
X_8 Green shear Strength	-	-	-	0.02380	-	-	-	0.04917	-	-
X_9 Bulk density of Mould	-	-	-	-	0.02405	-	-	-	0.04969	-
Intercept (Log.)	-0.11317	-0.17265	-0.19871	-0.32748	-0.27962	-0.25470	-0.29070	-0.42691	-0.328	-0.167
Antilog of A, constant	0.7691	0.6714	0.6324	0.4653	0.5243	0.5559	0.5117	0.3745	0.4528	0.6792
Multi-co-relation Coeff	0.9811	0.98063	0.98148	0.96865	0.96865	0.97148	0.97169	0.93524	0.93524	0.87727
Standard Error of Estimate.	0.30948	0.31398	0.30714	0.39832	0.39832	0.38014	0.37878	0.56761	0.56761	0.76960
Standard Error of Regression Coefficient X_4	0.54142	0.13358	0.09456	0.10219	0.10219	-	-	-	-	-
X_5	0.56086	-	-	-	-	0.20310	0.13198	0.15086	0.15086	-
X	-	0.12655	-	-	-	0.18573	-	-	-	0.46962
X7	-	-	0.07003	-	-	-	0.09436	-	-	0.36714
X8	-	-	-	0.00	-	-	-	0.00	-	-
X_9	-	-	-	-	0.00	-	-	-	0.00	-

[illegible]

MULTI CO – RELATION TABLE BETWEEN X_2 DEPENDENT VARIABLE AND INDEPENDENT VARIABLES :

Independent variables	Set I Regression Coeff.	Set II Regression Coeff.	Set III Regres-sion Coeff.	Set IV Regres-sion Coeff.	Set V Regression Coeff.	Set VI Regression Coeff.	Set VII Regression Coeff.
X_4 Green permeability No.	3.50652	1.69476	1.13103	-	-	-	-
X_5 Percent Moisture content	-2.48769	-	-	2.12393	1.56986	1.10547	1.10547
X_6 Mould Hardness No.	-	-0.66944	-	-1.07363	-	-	-
X_7 Green Compression Strength	-	-	-	-	-0.51338	-	-
X_8 Green Shear Strength	-	-	0.00	-	-	0.00	-
X_9 Bulk Density of Mould	-	-	-	-	-	-	-17.84332
Intercept (Log.)	-0.07856	-0.13715	-0.47274	-0.25736	-0.33944	-0.49981	228.91784
Antilog of A, constant	0.8337	0.7278	0.3367	0.5521	0.4517	0.3169	-
Multi co – relation coeff.	0.97156	0.99129	0.92763	0.98983	0.97678	0.87524	0.87524
Standard Error of estimate	0.42526	0.23649	0.67048	0.25486	0.38478	0.86878	0.86878
Standard Error of Regression Coefficient X_4	0.74397	0.10062	0.17211	-	-	-	-
X_5	0.77069	-	-	0.13616	0.13407	0.23090	0.23090
X_6	-	0.09532	-	0.12452	-	-	-
X_7	-	-	-	-	0.09585	-	-
X_8	-	-	0.00	-	-	0.00	-
X_9	-	-	-	-	-	-	0.00

Multi-co-relation Table between X_3 dependent variables and independent xsvariables

Independent variables		Set I Regression Coeff.	Set II Regression Coeff.	Set III Regression Coeff.	Set IV Regression Coeff.	Set V Regression Coeff.	Set VI Regression Coeff.	Set VII Regression Coeff.
X_4 Green permeability No		0.55396	0.90700	0.97925	-	-	-	-
X_5 Percent Moisture content		0.44537	-	-	1.13729	1.07909	1.01302	1.01302
X_6 Mould Hardness No.		-	0.08579	-	-0.13099	-	-	-
X_7 Green Compression Strength		-	-	-	-	0.07303	-	-
X_8 Gree shear Strength		-	-	0.00	-	-	0.00.	-
X_9 Bulk density of Mould		-	-	-	-	-	-	9.50483
Intercept (Log.)		-0.00533	-0.02223	-0.06524	-0.04229	-0.04906	-0.07187	-122.27877
Anti log of A, constant		0.9863	0.9484	0.8594	0.9057	0.8913	0.8472	-
Multi-co-relation coeff.		0.99190	0.99139	0.98985	0.99094	0.99141	0.98849	0.98849
Standard Error of Estimate		0.18506	0.19080	0.20706	0.19571	0.19051	0.22039	0.22039
Standard Error of Regression Coeff.	X_4	0.32375	0.08117	0.05312	-	-	-	-
	X_5	0.33538	-	-	0.10456	0.06638	0.05857	0.05857
	X_6	-	0.07690	-	0.09562	-	-	-
	X_7	-	-	-	-	0.04745	-	-
	X_8	-	-	0.00	-	-	0.00.	-
	X_9	-	-	-	-	-	-	0.00

Table - 7.1

Multi-co-relation table between X_1 dependent variable and independent variables

	Independent variables	Set I Regression Coeff.	Set II Regression Coeff.	Set III Regression Coeff.	Set IV Regression Coeff.	Set V Regression Coeff.
X_4	Green permeability No.	1.86545	1.71997	1.05843	1.[illegible]9043	-
X_5	Percent Moisture content	-0.74928	-0.62796	-0.00400	-	1.44494
X_6	Mould Hardness No.	-0.11367	-	-	-0.04960	-0.26849
X_7	Green compression strength	-	-0.08847	-	-0.12641	-0.15009
X_8	Green shear strength	-	-	-	-	-
X_9	Bulk density of mould	-	-	0.00167	-	-
Intercept (Log.)		-0.12786	- 0.14346	-0.30365	-0.19209	-0.27021
Anti log of A, constant		0.7447	0.7178	0.4966	0.6412	0.5358
Multi-co-relation coefficient		0.98165	0.98260	0.96883	0.98152	0.97271
Standard Error of Estimate		0.33021	0.32159	0.42897	0.33136	0.40179
Standard Error of Regression Coefficient	X_4	1.02936	0.89266	0.11206	0.21123	-
	X_5	1.29261	1.01022	0.00018	-	0.32570
	X_6	0.28748	-	-	0.41864	0.57038
	X_7	-	0.12711	-	0.23685	0.29082
	X_8	-	-	-	-	-
	X_9	-	-	0.00095	-	-

Multi - co - relation study between X_2 dependent variable and independent variables

Independent variables		Set I Regression Coefficient	Set II Regression Coefficient	Set III Regression Coefficient	Set IV Regression Coefficient
4. Green permeability No.		1.03086	1.78092	1.68133	-
5. Percent Moisture content		0.84150	-	-	2.12812
6. Mould Hardness No.		-0.83535	-0.43317	-0.63556	-1.08279
7. Green compression strength		-	-0.31649	-0.02022	0.00497
8. Green Shear Strength		-	-	-	-
9. Bulk density of mould		-	-	-	-
Intercept (Log.)		-0.18721	-0.18697	-0.14027	-0.25684
Antilog A, constant		0.6486	0.6501	0.7228	0.5534
Multi co-relation coeffic.		0.99230	0.98606	0.99131	0.98988
Standard Error of Estimate		0.24022	0.32273	0.25518	0.27529
Standard Error of Regression Coefficient	X_4	0.74884	0.89583	0.16257	-
	X_5	0.94035	1.01381	-	0.22315
	X_6	0.20913	-	0.32239	0.39079
	X_7	-	0.12756	0.18239	0.19925
	X_8	-	-	-	-
	X_9	-	-	-	-

Table - 7.3

Multi - co - relation table between X_3 dependent variable and independent variables

Independent variables		Set I Regression Coeff.	Set II Regression Coeff.	Set III Regression Coeff.	Set IV Regression Coeff.
X_4	Green permeability No.	0.52617	0.39210	0.84104	-
X_5	Percent Moisture Content	0.48268	0.63808	-	1.06388
X_6	Mould Hardness No.	-0.00937	-	0.25218	0.02949
X_7	Green compression Strength	-	-0.02969	-0.09932	-0.08715
X_8	Green shear Strength	-	-	-	-
X_9	Bulk density of mould	-	-	-	-
Intercept (Log.)		-0.00642	-0.01548	-0.00695	-0.05129
Antilog of A, constant		0.9840	0.9638	0.9840	0.8872
Multi co-relation-coefficient		0.99187	0.99209	0.99204	0.99143
Standard Error of Estimate		0.20021	0.19756	0.19812	0.20563
Standard error of Regression coefficient	X_4	0.62411	0.54838	0.12629	-
	X_5	0.78372	0.62060	-	0.16669
	X_6	0.17430	-	0.25030	0.29191
	X_7	-	0.07808	0.14161	0.14884
	X_8	-	-	-	-
	X_9	-	-	-	-

Best relationship between two independent variables for two different sets of dependent variables :

I. $X_1 = 0.7691 \; X_4^{2.20235} \; X_5^{-1.20228}$

II. $X_1 = 0.6714 \; X_4^{1.27439} \; X_6^{-0.26137}$

III. $X_1 = 0.6324 \; X_4^{1.16851} \; X_7^{-0.15301}$

IV. $X_1 = 0.4653 \; X_4^{1.05429} \; X_8^{0.02380}$

V. $X_1 = 0.5248 \; X_4^{1.05429} \; X_9^{0.02405}$

VI. $X_1 = 0.5359 \; X_5^{1.57136} \; X_6^{-0.54488}$

VII. $X_1 = 0.5117 \; X_5^{1.30651} \; X_7^{-0.27862}$

VIII. $X_1 = 0.3745 \; X_5^{1.05448} \; X_8^{0.04917}$

IX. $X_1 = 0.4528 \; X_5^{1.05448} \; X_9^{0.4969}$

X. $X_1 = 0.6792 \; X_6^{2.01622} \; X_7^{-1.12040}$

I. $X_2 = 0.8337 \; X_4^{3.50652} \; / \; X_5^{2.48769}$

II. $X_2 = 0.7273 \; X_4^{1.69476} \; / \; X_6^{0.66944}$

III. $X_2 = 0.3367 \; X_4^{1.13103} \; X_8^{0.00}$

IV. $X_2 = 0.5521 \; X_5^{2.12393} \; / \; X_6^{1.07363}$

V. $X_2 = 0.4517 \; X_5^{1.56986} \; / \; X_7^{0.51338}$

VI. $X_2 = 0.3169 \; X_5^{1.10547} \; / \; X_8^{0.00}$

I. $X_3 = 0.9863 \; X_4^{0.55396} \; X_5^{0.44537}$

II. $X_3 = 0.9484 \; X_4^{0.90700} \; X_6^{0.08579}$

III. $X_3 = 0.8590 \; X_4^{0.97925} \; X_8^{0.00}$

IV. $X_3 = 0.9057 \; X_5^{1.13729} \; / \; X_6^{0.13099}$

V. $X_3 = 0.8913 \; X_5^{1.07909} \; X_7^{0.07303}$

VI. $X_3 = 0.8472 \; X_5^{1.01302} \; X_8^{0.00}$

Best relationship between three independent variable for DIFFERENT SETS OF DEPENDENT VARIABLES :

I. $X_1 = 0.7447 \; X_4^{1.86545} \; X_5^{-0.74928} \; X_6^{-0.11367}$

II. $X_1 = 0.7178 \; X_4^{1.71997} \; X_5^{-0.62796} \; X_7^{-0.08847}$

III. $X_1 = 0.4966 \; X_4^{1.05843} \; X_5^{-0.00400} \; X_9^{0.00167}$

IV. $X_1 = 0.6412 \; X_4^{1.19043} \; X_6^{-0.04960} \; X_7^{-0.12641}$

V. $X_1 = 0.5358 \; X_5^{1.44494} \; X_6^{-0.26349} \; X_7^{0.15009}$

I. $X_2 = 0.6486 \; X_4^{1.03086} \; X_5^{0.84150} \; X_6^{-0.83535}$

II. $X_2 = 0.6501 \; X_4^{1.78092} \; X_5^{-0.43317} \; X_7^{-0.31649}$

III. $X_2 = 0.7328 \; X_4^{1.68133} \; X_5^{-0.63556} \; X_7^{-0.02022}$

IV. $X_2 = 0.5534 \; X_5^{2.12812} \; X_6^{-1.08279} \; X_7^{0.00497}$

I. $X_3 = 0.9840 \; X_4^{0.52617} \; X_5^{0.48268} \; X_6^{-0.00937}$

II. $X_3 = 0.9638 \; X_4^{0.39210} \; X_5^{0.63808} \; X_7^{-0.02969}$

III. $X_3 = 0.9840 \; X_4^{0.84104} \; X_6^{0.25218} \; X_7^{-0.09932}$

IV. $X_3 = 0.8872 \; X_5^{1.06388} \; X_6^{0.02949} \; X_7^{-0.08715}$

Best relationship between dependent variables and independent variables out of the different sets of dependent variables :

1. $X_1 = 0.6324 \quad X_4^{1.16851} \quad X_7^{-0.15301}$

2. $X_2 = 0.7278 \quad X_4^{1.69476} \quad X_6^{-0.66944}$

III. $X_3 = 0.8913 \quad X_5^{1.07909} \quad X_7^{0.07303}$

IV. $X_1 = 0.6412 \quad X_4^{1.19043} \quad X_6^{-0.04950} \quad X_7^{-0.12641}$

V. $X_2 = 0.7228 \quad X_4^{1.68153} \quad X_6^{-0.63556} \quad X_7^{-0.02022}$

VI. $X_3 = 0.9840 \quad X_4^{0.84104} \quad X_6^{0.25218} \quad X_7^{-0.09932}$

Sensitivity Test

Value of dependent variables , X_1, X_2 , X_3 in percentage if 1% change in independent variable (keeping other variable constant)

I. $X_1 = 0.6324 \quad X_4^{1.16841} \quad X_7^{-0.15301}$

$$X_1 = X_4^{1.16851} = (1.01)^{1.16851} = 1.01169$$

$$1.01169 - 1 = 0.01169 \times 100 = 1.169\%$$

$$X_1 = X_7^{-0.15301} = (1.01)^{-0.15301} = 0.856$$

$$= 0.856 - 1 = -0.144 \times 100 = -14.4\%$$

$$\text{II.}\quad X_2 = 0.7278 \quad X_4^{1.69476} \quad X_6^{-0.66944}$$

$$X_2 = X_4^{1.69476} = (1.01)^{1.69476} = 1.0170$$

$$= 1.0170 - 1 = 0.0170 \times 100 = 1.70\%$$

$$X_2 = X_6^{-0.66944} = (1.01)^{-0.66944} = 0.34056$$

$$= 0.34056 - 1 = -0.65944 \times 100 = -65.944\%$$

$$\text{III.}\quad X_3 = 0.8913 \quad X_5^{1.07909} \quad X_7^{0.07303}$$

$$X_3 = X_5^{1.07909} = (\ 1.01\ )^{1.07909} = 1.0107$$

$$= 1.0107 - 1 = 0.0107 \times 100 = 1.07\%$$

$$X_3 = X_7^{0.07303} = (\ 1.01\ )^{0.07303} = 1.00073$$

$$= 1.00073 - 1 = 0.00073 \times 100 = 0.073\%$$

$$\text{IV.}\quad X_1 = 0.6412 \quad X_4^{1.19043} \quad X_6^{-0.04960} \quad X_7^{-0.12641}$$

$$X_1 = X_4^{1.19043} = (1.01)^{1.19043} = 1.0119$$

$$= 1.0119 - 1 = 0.0119 \times 100 = 1.19\%$$

$$X_1 = X_6^{-0.04960} = (1.01)^{-0.04960} = 0.9604$$

$$= 0.9604 - 1 = -0.0396 \times 100 = -3.96\%$$

$$X_1 = X_7^{-0.12641} = (1.01)^{-0.12641} = 0.88359$$

$$= 0.88359 - 1 = -0.11641 \times 100 = -11.641\%$$

$$X_2 = 0.7228 \quad X_4^{1.68133} \quad X_6^{-0.63556} \quad X_7^{-0.02022}$$

$$X_2 = X_4^{1.68133} = (1.01)^{1.68133} = 1.0168 - 1 =$$

$$= 0.0168 \times 100 = 1.68\%$$

$$X_2 = X_6^{-0.63556} = (1.01)^{-0.63556} = 0.37444$$

$$= 0.37444 - 1 = -0.62556 \times 100 = -62.556\%$$

$$X_2 = X_7^{-0.02022} = (1.01)^{-0.02022} = 0.98978$$

$$= 0.98978 - 1 = -0.01022 \times 100 = -1.022\%$$

$$X_3 = 0.9840 \quad X_4^{0.84104} \quad X_6^{0.25218} \quad X_7^{-0.09932}$$

$$X_3 = X_4^{0.84104} = (1.01)^{0.84104} = 1.0084$$

$$= 1.0084 - 1 = 0.0084 \times 100 = 0.84\%$$

$$X_3 = X_6^{0.25218} = (1.01)^{0.25218} = 1.0025$$

$$= 1.0025 - 1 = 0.0025 \times 100 = 0.25\%$$

$$X_3 = X_7^{-0.09932} = (1.01)^{-0.09932} = 0.91068$$

$$= 0.91068 - 1 = 0.08932 \times 100 = 8.932\%$$

Table - 7.4

Sensitivity of variables

1% change in independent variable (Keeping other variable constant)		% change in dependent variable		
1. Green Permeability No.	(X_4)	1.169%	Change in Brinell hardness No.	(X_1)
2. Green compression strength	(X_7)	-14.4%	,,	
3. Green permeability No.	(X_4)	1.70%	Change in casting density	(X_2)
4. Green mould hardness No.	(X_6)	-65.944%	,,	
5. Percent moisture content	(X_5)	1.07%	Change in tensile strength	(X_3)
6. Green compression strength	(X_5)	0.073%	,,	
7. Green permeability No.	(X_4)	1.19%	Change in Brinell hardness No.	(X_1)
8. Green mould hardness No.	(X_6)	-3.96%	,,	
9. Green compression strength	(X_7)	-11.64%	,,	
10. Green permeability No.	(X_4)	1.68%	Change in casting density	(X_2)
11. Green mould hardness No.	(X_6)	-62.556%	Change in casting density	(X_2)
12. Green compression strength	(X_7)	-1.022%	,,	
13. Green permeability No.	(X_4)	0.34%	Change in tensile strength	(X_3)
14. Green mould hardness No.	(X_6)	0.25%	,,	
15. Green compression strength	(X_7)	-8.92%	,,	

CONCLUSION

In the first phase of this work the effect of mulling time on various physical properties of moulding sand with the variation in clay content and moisture content has been studied and test results have been reported in chapter II. It h was fond that the moisture content effected more on various physical properties of moulding sand than clay content.

A detailed study of the effect of physical properties of moulding sand on casting soundness parameters have been experimentally studied. It has been concluded that a given moisture content the casting soundness parameters increases at a certain extent ,tensile strength and Brinell hardness number attains a maximum value around a moisture content of 6% and 4% respectively and decreases with further increase in moisture content . Tensile strength and Brinell hardness increases constantly with increase in green permeability but casting density increases gradually, attains a maximum value at a green permeability no. of 8.8 andsubsequently decreases with further increase in green permeability. Green compression strength and green mould hardness also affact the casting soundness parameters but it was found that the green permeability and moisture content are more effective on casting soundness parameters than green compression strength and green mould hardness as given from figure (15 to 19).

Through multiple regression analysis it was found that the casting density is most sensitive casting soundness parameter with 1% change in green permeability number, others casting soundness parameter such as Brinell hardness no. and tensile strength are less sensitive with 1% change in various physical properties of moulding sand. The sensitivity of other parameters are tabulated in table 7.4.

Thebest relationship develop through multiple regression technique was t found to be between tensile strength and percent moisture content, green compression strength are as follows :

$$X_3 = 0.8913 \quad X_5^{1.07909} \quad X_7^{0.07303}$$

Where,

X_3 = Tensile strength

X_5 = Moisture content

X_7 = Green compression strength

This relationship is selected on the basis of that the value of Multi-co-relation coefficient is 0.99141 a maximum value as well as the value of standard error of regression coefficient for moisture content is 0.06638 and for green compression strength is 0.04745 a minimum value.

APPENDIX - A

```
// JOB T                                                     CC080  R          K,NAIM AHMAD

// FOR
*LIST SOURCE PROGRAM
      SUBROUTINEDATA(M,D)        DIMENSIOND(1)        COMMONMX,MY        READ(MY,1)(D(I),I=1,M)       WRITE(MX,2)(D(I),I=1,M
     &)
1     FORMAT(F4.2/9(F8.0))
2     FORMAT(1H ,'THE VALUES OF D(I)=',13(F4.2,1X))        RETURN       END

CORE REQUIREMENTS FOR DATA
 COMMON       2  VARIABLES       2  PROGRAM      82

*STORE       WS  UA  DATA                    &DCT-50& .AUTO-STORE.
CART ID 0008   DB ADDR  5318   DB CNT   0006

// FOR
*LIST SOURCE PROGRAM
C     MULTIPLE  LINEAR  REGRESSION
C     DIMENSION OF M
      DIMENSIONX(666)       DIMENSIONA(10,7)
C     DIMENSION M*M
      DIMENSIONRX(100)      DIMENSIONXBAR(7),STD(7),D(7),RY(7),ISAVE(7),B(7),SB(7),T(7),W(7)
C     DIMENSION R(M*(M+1)/2)
      DIMENSIONR(55)
C      DIM. EQUAL TO 10.
      DIMENSIONANS(10)       COMMONMX,MY
15    FORMAT(2I2)        READ(8,15)MX,MY
1     FORMAT(A4,A2,I5,2I2)
2     FORMAT(////25H MULTIPLE REGRESSION     A4,A2//6X,14HSELECTION     I2//)
3     FORMAT(//9H VARIABLE,5X,4HMEAN,6X,8HSTANDARD,6X,11HCORRELATION,  4X,
     &                11H REGRESSION,4X,10HSTD..ERROR,5X,8HCOMPUTED/6H   NO.,13X,       9HDEVIATION,7X,6H VS.Y,7X,11HCO
     &EFFICIENT,3X,12HOF REG.COEF.,      3X,7HT.VALUE)
4     FORMAT(/,I4,6F14.5)
5     FORMAT(/,10H DEPENDENT)
6     FORMAT(///10H INTERCEPT,13X,F13.5//23H MULTIPLE CORRELATION  ,F13.5//23H STD ERROR OF ESTIMATE,F13.5//)
7     FORMAT(//,21X,39HANALYSIS OF VARIANCESFOR THE REGRESSION//       5X,19HSOURCE OF VARIATION,7X,7HDEGREES,7X,5HSUM O
     &F,10X,4HMEAN,     13X,7HF VALUE/30X,10HOF FREEDOM,4X,6HSQURES,9X,6HSQURES)
8     FORMAT(/30H ATTRIBUTABLE TO REGRESSION    ,I6,3F16.5/40H            DEVIATION FROM REGRESSION       ,2F 6.5)
9     FORMAT(/5X,5HTOTAL,     I6,F16.5   )
10    FORMAT(36I2)
11    FORMAT(/,15X,18HTABLE OF RESIDUALS//9H CASE NO.,5X,7HY VALUE,    5X,10HY ESTIMATE,6X,8HRESIDUAL)
12    FORMAT(I6,F15.5,2F14.5)
13    FORMAT(////52H NUMBER OF SELECTION NPT SPECIFIED    JOB TERMINATED.)
14    FORMAT(//51H THE MATRIX IS SINGULAR    THIS SELECTIONIS SKIPPED.)
999   FORMAT(7F10.0)
C     PROGRAMME PARAMETETS
100   READ(8,1)PR,PR1,N,M,NS
      DO4444K=1,10       READ(8,999)(X(I),I=1,7)
      DO1234MK=1,7       A(K,MK)=ALOG(X(MK))
1234  CONTINUE
4444  CONTINUE
888   FORMAT(1H ,5F12.2)       WRITE(5,888)((A(I,J),J=1,7),I=1,10)
C     ******          PR.....PROB NAME
C     ******          PR1....NO. OF PROB
C     ******          N......NO OF OBS.
C     ******          M........NO OF VARIABLES
C     ******          NS.......NO OF SELECTION
```

```
      ID=1       CALLCORRE(N,M,IO,A,XBAR,STD,RX,R,D,B,T)
      IF(NS)108,108,109
108   WRITE(MX,13)
      GOTO300
109   DO200I=1,NS        WRITE(MX,2)PR,PR1,I
C   NRESI...... OPT. CODE FOR TABLE
C     0   IF  NOT ,  1  IF  REQUIRED
C      NDEP..... DEPENDENT VAR.
      READ(MY,10)NRESI,NDEP,K,(ISAVE(J),J=1,K)
C     K...... NO OF IND. VAR. INCLUDED
C      ISAVE...... A VECTOR CONTAING THE DEP. VARS. INCLUDED
      CALLORDER(M,R,NDEP,K,ISAVE,RX,RY)       CALLMINV(RX,K,DET,B,T)
      IF(DET)112,110,112
110   WRITE(MX,14)
      GOTO200
112   CALLMULTR(N,K,XBAR,STD,D,RX,RY,ISAVE,B,SB,T,ANS)       MM=K+1       WRITE(MX,3)
      DO115J=1,K       L=ISAVE(J)
115   WRITE(MX,4)L,XBAR(L),STD(L),RY(J),B(J),SB(J),T(J)       WRITE(MX,5)       L=ISAVE(MM)       WRITE(MX,4)L,XBAR(L),S
     &TD(L)       WRITE(MX,6)ANS(1),ANS(2),ANS(3)       WRITE(MX,7)       L=ANS(8)       WRITE(MX,8)K,ANS(4),ANS(6),ANS(1
     &0),ANS(7),ANS(9)       L=N-1       SUM=ANS(4)+ANS(7)       WRITE(MX,9)L,SUM
      IF(NRESI)200,200,120
120   WRITE(MX,2)PR,PR1,I        WRITE(MX,11)       MM=ISAVE(K+1)
      DO140II=1,N
C       CALL DATA(M,W)
      DO1000IJ=1,M
1000  W(IJ)=A(II,IJ)       SUM=ANS(1)
      DO130J=1,K       L=ISAVE(J)
130   SUM=SUM+W(L)*B(J)       RESI=W(MM)-SUM
140   WRITE(MX,12)II,W(MM),SUM,RESI
200   CONTINUE
      GOTO100
300   CALLEXIT       END

CORE REQUIREMENTS FOR
 COMMON      2  VARIABLES    1956  PROGRAM    1030

END OF COMPILATION

// XEQ
```

4.21	4.30	4.26	4.14	4.23
4.22	4.14	0.97	0.96	0.99
1.02	0.98	0.95	0.82	0.33
0.60	0.62	0.55	0.54	0.23
0.14	2.25	2.32	2.17	2.11
2.02	1.58	-0.11	1.09	1.38
1.79	2.07	2.30	2.48	2.63
3.80	3.57	3.95	3.82	3.82
3.91	4.00	2.28	2.39	2.37
2.44	2.33	2.16	2.37	2.02
2.04	2.02	2.23	2.12	1.94
2.04	0.48	0.50	0.55	0.54
0.55	0.58	0.65	0.18	-0.91
1.16	0.87	1.38	3.38	4.77

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